INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
RICE UNIVERSITY

INTERVARIETAL DIFFERENCES
OF METHANE EMISSION RELATED TO PLANT
PARAMETERS IN IRRIGATED RICE CULTIVATION

by

CYLETTE R. WILLIS

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

DOCTOR OF PHILOSOPHY

APPROVED, THESIS COMMITTEE

[Signature]
Ronald L. Sass, Professor, Director
Ecology and Evolutionary Biology

[Signature]
Frank M. Fisher, Professor
Ecology and Evolutionary Biology

[Signature]
Arthur A. Few, Jr., Professor
Space Physics and Astronomy

Houston, Texas
May, 1995
ABSTRACT

INTERVARIETAL DIFFERENCES
OF METHANE EMISSION RELATED TO PLANT
PARAMETERS IN IRRIGATED RICE CULTIVATION

by

Cylette R. Willis

Field and laboratory experiments were conducted with the following ten cultivars of rice: Lebonnet, Lemont, Dawn, Katy, Della, IR36, Mars, Brazos, Labelle and Jasmine. For each variety, components of biomass, root porosity and methane emission were observed throughout the entire growing season and yield was determined at harvest. Methane emission differed among cultivars by as much as a factor of 2.4 and resulted in two distinct emission groups. Significant differences were also found for biomass among cultivars, although these differences did not coincide with the differences that were observed for emission among cultivars. Methane emission correlated strongly with aboveground live vegetative biomass within most varieties until heading and among cultivars within emission groups to heading. Emissions showed less correlation with biomass during ripening and may have been affected by other factors within the system at this time. Methane emission appeared to be consistently proportional to grain production among
cultivars, when determined per gram biomass, and may be related through processes of carbohydrate partitioning. Root porosity did not appear to be associated with observed differences or trends in methane emission.
ACKNOWLEDGMENTS

I offer heartfelt gratitude to the many people who assisted and encouraged me in this work. Their support, which challenged and inspired, was a foundation, a refuge, a boot, and a light throughout the project's completion. Among these, I am thankful to Ron Sass, the finest teacher I've known, for his guidance, questions and humor; to Frank Fisher, for his creative and earnest approach to science, and to Arthur Few, for his thoughtful comments and kind help.

I appreciate the work of Fred Turner and Mike Jund of the Texas A&M Agricultural and Research Center in Beaumont, Texas. They were important and accessible resources in the office as well as the field.

Kris Johnson, Rosine Hall and Joan Strassman shared significant amounts of time, expertise and empathy during all phases this project. Their contributions were invaluable.

In addition, I thank Yao Huang for the availability of his data and experience and Sandra Lewis and Lief Sigren for their encouragement. Anne Goldstein, Evelyn Brown and Alex Kagan of Baylor College of Medicine provided training, photographic equipment and lab space. I also recognize the efforts of Alice Lim and Jeff Wu, undergraduate
assistants, who were tenacious and cheerful during the demanding process of data collection and preparation.

Finally, I am deeply grateful to friends and family for their unyielding strength and support. Ann Neyland, Sandy and Richard King, and Laurie Feinswog exceeded the boundaries of typical friendship. My children, Travis, Bryant and Will Chambers, and my mother were patient and helpful companions. My best friend, Amy Rowland, has been an intellectual and affective constant. I am blessed and I thank God.
TABLE OF CONTENTS

1 INTRODUCTION .................................................................................................................. 1
1.1 Methane and Rice Cultivation ..................................................................................... 2
1.2 Rice Plant Morphology and Life History ................................................................. 3
1.3 Plant Development, Biomass and Methane Emission .................................................. 13
1.4 Aerenchyma Tissue and Methane Emission ............................................................. 15
1.5 Exudation, Senescence and Methane Emission ......................................................... 18
1.6 Rice Varietal Differences and Methane Emission ................................................... 21

2 FIELD DESCRIPTION AND METHODS ................................................................. 23
2.1 Field Description and Management ........................................................................... 23
2.2 Field Parameters ........................................................................................................ 28
2.3 Cultivars ..................................................................................................................... 28
2.4 Determination of Tiller Number .................................................................................. 31
2.5 Biomass Measurement ............................................................................................... 32
2.6 Root Porosity ............................................................................................................... 36
2.7 Relative Chlorophyll ................................................................................................... 41
2.8 Root Observations ...................................................................................................... 41
2.9 Determination of Cross-Sectional Area of Aerenchyma .......................................... 43
3 RELATED RESEARCH

3.1 Measurement of Methane Emissions

3.2 Grain Yield Determination

3.3 Cultivar Studies, 1994

4 RESULTS

4.1 Plant Development

4.2 Plant Height and Tiller Count

4.3 Biomass Results

4.3.1 Seasonal biomass trends within and among cultivars

4.3.2 Biomass per stem

4.3.3 Relationship between aboveground and belowground biomass

4.3.4 Biomass partitioning within and among cultivars

4.3.5 Aboveground dead biomass among cultivars

4.3.6 Biomass variation among cultivars

4.3.7 Biomass differences among cultivars

4.4 Root Porosity

4.5 Relative Chlorophyll

4.6 Qualitative observations of root and aerenchyma development
5 RESULTS OF RELATED RESEARCH ........................................... 112
  5.1 Field Parameters ...................................................... 112
  5.2 Methane Emission ..................................................... 114
  5.3 Grain Yield ............................................................. 118
  5.4 Biomass and Emission Results for 1994 Cultivar
      Studies ........................................................................ 119

6 DISCUSSION ........................................................................ 123
  6.1 Biomass Partitioning Trends Among Cultivars ............... 123
  6.2 Methane Emission Trends Among Cultivars ..................... 125
  6.3 Variation in Emission Among Cultivars ......................... 131
  6.4 Emission Differences Among Cultivars ......................... 134
  6.5 Comparison of 1993 and 1994 Biomass Results ............. 143
  6.6 Biomass and Methane Emission Within Cultivars ............ 150
  6.7 Biomass and Methane Emission Among Cultivars ............ 163
  6.8 Biomass and Grain Yield Among Cultivars ..................... 177
  6.9 Biomass, Emission and Grain Yield Within and
      Among Cultivars .......................................................... 180
  6.10 Root Porosity and Relative Chlorophyll ....................... 186
  6.11 Conclusions .............................................................. 189

BIBLIOGRAPHY ..................................................................... 192

APPENDIXES ........................................................................ 195

Appendix 1: Table A1(I) and (II). Summary of
Seasonal Biomass Partitioning for
Samples 1, 2, 4, 6 and 7................................. 195

Appendix 2: Table A2. Summary of Seasonal
Biomass Partitioning for Samples 3, 5
and 8.......................................................... 197

Appendix 3: Table A3 (I) and (II). Average Daily
Emission on Days of Biomass
Collection..................................................... 198

Appendix 4: Table A4. Grain Yield with Standard
Deviation and Harvest Index. ......................... 199

Appendix 5: 1994 Emission and Biomass for
Lemont, Mars and Labelle. (from
Huang, Y. 1994. unpublished).......................... 200
LIST OF TABLES

Table 1. Lake Charles soil analysis ................................................................. 25
Table 2. 1993 field management and plant development ......................... 27
Table 3. Characteristics of experimental cultivars .............................. 30
Table 4. Plant development for ten cultivars ........................................... 49
Table 5. 1993 biomass data for ten cultivars ........................................... 96
Table 6. Total seasonal emission and average daily emission
   for ten cultivars. .................................................................................. 116
Table 7. Grain yield of experimental cultivars ...................................... 118
Table 8. 1994 Plant development for Lemont, Mars and
   Labelle ............................................................................................... 119
Table 9. 1993 Emission data for ten cultivars ........................................ 132
Table 10. 1993 and 1994 plant development for three
   cultivars .................................................................................................. 143
Table 11. 1993 and 1994 biomass data for ten cultivars.
   (1994 data: Huang, Y., unpublished.) .................................................. 145
Table 12. 1993 and 1994 emission data for ten
   cultivars .................................................................................................. 147
Table 13. Pearson correlation coefficient for methane emission
   with four biomass categories during three time
   periods ...................................................................................................... 151
Table 14. Slopes of correlation between aboveground live
   vegetative biomass and emission ........................................................ 154
LIST OF FIGURES

Figure 1. Three and two phase model of rice plant
development from Yoshida, 1981. ............................ 5

Figure 2. Rice plant growth types from Yoshida, 1981. ................. 9

Figure 3. Methane production, emission and oxidation
associated with rice plants from Schütz et al.,
1991. ........................................................................... 16

Figure 4. 1994 field plan for cultivar study. .................................. 24

Figure 5 ........................................................................... 37

5a. Comparison of aboveground live vegetative biomass
samples 2 and 3.

5b. Comparison of aboveground live vegetative biomass
samples 7 and 8.

Figure 6. Stem count and plant height-Lebonnet. .......................... 51

Figure 7. Stem count and plant height-Lemont. .............................. 52

Figure 8. Stem count and plant height-Dawn. ............................... 53

Figure 9. Stem count and plant height-Katy. ................................. 54

Figure 10. Stem count and plant height-Della. ............................... 55

Figure 11. Stem count and plant height-IR36. ............................... 56

Figure 12. Stem count and plant height-Mars. ............................... 57

Figure 13. Stem count and plant height-Brazos. ............................ 58

Figure 14. Stem count and plant height-Labelle. ............................ 59

Figure 15. Stem count and plant height-Jasmine. ............................ 60
Figure 16. .................................................................................. 62
  16a. Comparison of post-heading tiller number and
       panicle number.
  16b. Percentage of tillers with panicles.

Figure 17. .................................................................................. 64
  17a. Post-heading tiller count.
  17b. Post-heading plant height.

Figure 18. Seasonal aboveground live vegetative biomass............. 66

Figure 19. .................................................................................. 67
  19a. Seasonal root biomass (0-10 cm).
  19b. Seasonal root biomass (0-10 cm).

Figure 20. .................................................................................. 69
  20a. Aboveground live vegetative biomass to 73 days
       past flood for Lebonnet.
  20b. Aboveground live vegetative biomass to 73 days
       past flood for Lebonnet (smoothed data).

Figure 21. .................................................................................. 70
  21a. Aboveground live vegetative biomass to 73 days
       past flood for Lemont.
  21b. Aboveground live vegetative biomass to 73 days
       past flood for Lemont (smoothed data).

Figure 22. .................................................................................. 71
  22a. Aboveground live vegetative biomass to 73 days
       past flood for Dawn.
22b. Aboveground live vegetative biomass to 73 days past flood for Dawn (smoothed data).

Figure 23. ........................................................................................................ 72

23a. Aboveground live vegetative biomass to 73 days past flood for Katy.

23b. Aboveground live vegetative biomass to 73 days past flood for Katy (smoothed data).

Figure 24. ........................................................................................................ 73

24a. Aboveground live vegetative biomass to 73 days past flood for Della.

24b. Aboveground live vegetative biomass to 73 days past flood for Della (smoothed data).

Figure 25. ........................................................................................................ 74

25a. Aboveground live vegetative biomass to 73 days past flood for Mars.

25b. Aboveground live vegetative biomass to 73 days past flood for Mars (smoothed data).

Figure 26. ........................................................................................................ 75

26a. Aboveground live vegetative biomass to 73 days past flood for IR36.

26b. Aboveground live vegetative biomass to 73 days past flood for IR36 (smoothed data).

Figure 27. ........................................................................................................ 76

27a. Aboveground live vegetative biomass to 73 days past flood for Brazos.
27b. Aboveground live vegetative biomass to 73 days past flood for Brazos (smoothed data).

Figure 28. ........................................................................................................ 77

28a. Aboveground live vegetative biomass to 73 days past flood for Labelle.

28b. Aboveground live vegetative biomass to 73 days past flood for Labelle (smoothed data).

Figure 29. ........................................................................................................ 79

29a. Aboveground live vegetative biomass to 73 days past flood for Jasmine.

29b. Aboveground live vegetative biomass to 73 days past flood for Jasmine (smoothed data).

Figure 30. Proportion of total root biomass (0-5 cm) at 63 days past flood. ................................................................. 80

Figure 31. Seasonal total live biomass for ten cultivars......................... 81

Figure 32. ........................................................................................................ 83

32a. Aboveground live vegetative biomass and root biomass (0-10 cm) per tiller at 63 days past flood.

32b. Aboveground live vegetative biomass per tiller and aboveground live vegetative biomass per m² at 63 days.

Figure 33. ........................................................................................................ 85

33a. Average aboveground live vegetative biomass and root biomass to 63 days past flood (normalized).

33b. Seasonal root to shoot ratio for ten cultivars.
Figure 34. ......................................................................................................................... 87
  34a. Seasonal partitioning of biomass for Lebonnet.
  34b. Seasonal partitioning of biomass for Lemont.
Figure 35. ......................................................................................................................... 88
  35a. Seasonal partitioning of biomass for Dawn.
  35b. Seasonal partitioning of biomass for Katy.
Figure 36. ......................................................................................................................... 89
  36a. Seasonal partitioning of biomass for Della.
  36b. Seasonal partitioning of biomass for IR36.
Figure 37. ......................................................................................................................... 90
  37a. Seasonal partitioning of biomass for Mars.
  37b. Seasonal partitioning of biomass for Brazos.
Figure 38. ......................................................................................................................... 91
  38a. Seasonal partitioning of biomass for Labelle.
  38b. Seasonal partitioning of biomass for Jasmine.
Figure 39. ......................................................................................................................... 92
  39a. Average seasonal partitioning of biomass
(normalized).
  39b. Average biomass partitioning (normalized).
Figure 40. Aboveground dead biomass as a percentage of total
  biomass (with and without panicle) at 70 days past
  flood. ................................................................................................................................. 94
Figure 41. Comparison of mature aboveground live vegetative
  biomass............................................................................................................................. 98
Figure 42. ......................................................................................................................... 100
42a. Root porosity during the season for Lebonnet.
42b. Root porosity during the season for Lemont.

Figure 43. ........................................................................................................ 101
  43a. Root porosity during the season for Dawn.
  43b. Root porosity during the season for Katy.

Figure 44. ........................................................................................................ 102
  44a. Root porosity during the season for Della.
  44b. Root porosity during the season for IR36.

Figure 45. ........................................................................................................ 103
  45a. Root porosity during the season for Mars.
  45b. Root porosity during the season for Brazos.

Figure 46. ........................................................................................................ 104
  46a. Root porosity during the season for Labelle.
  46b. Root porosity during the season for Jasmine.

Figure 47. Root porosity at 30 and 43 days past flood. ............................... 106
Figure 48. Root porosity at heading for ten cultivars. ................................. 107
Figure 49. ........................................................................................................ 109
  49a. Relative chlorophyll during the season.
  49b. Relative chlorophyll at heading.

Figure 50. Cross-section of stem aerenchyma. .............................................. 111
Figure 51. Mean seasonal air and soil temperature. ................................. 113
Figure 52. Mean seasonal water depths for two cultivar
  groups. ........................................................................................................ 115
Figure 53. Comparison of seasonal methane emissions for ten
  cultivars. .................................................................................................... 117
Figure 54. 1993 grain yield................................................................. 120

Figure 55. ...................................................................................... 122

55a. 1994 aboveground live vegetative biomass for
Lemont, Mars and Labelle (1994 data: Huang, Y.,

55b. 1994 average daily emission for Lemont, Mars and
Labelle.

Figure 56. ...................................................................................... 124

56a. Comparison of average aboveground live
vegetative, panicle and total biomass growth.

56b. Comparison of growth of aboveground vegetative
live biomass (16-32 days) and panicle biomass (51-
70 days).

Figure 57. ...................................................................................... 126

57a. Average daily emission for Lebonnet to 73 days
past flood.

57b. Average daily emission for Lemont to 73 days past
flood.

Figure 58. ...................................................................................... 127

58a. Average daily emission for Dawn to 73 days past
flood.

58b. Average daily emission for Katy to 73 days past
flood.

Figure 59. ...................................................................................... 128
59a. Average daily emission for Della to 73 days past flood.

59b. Average daily emission for IR36 to 73 days past flood.

Figure 60. ........................................................................................................ 129

60a. Average daily emission for Mars to 73 days past flood.

60b. Average daily emission for Brazos to 73 days past flood.

Figure 61. ........................................................................................................ 130

61a. Average daily emission for Labelle to 73 days past flood.

61b. Average daily emission for Jasmine to 73 days past flood.

Figure 62. Comparison of seasonal methane emissions for ten cultivars. ........................................................................................................ 135

Figure 63. Comparison of emissions from pd to heading for ten cultivars. ........................................................................................................ 136

Figure 64. Average daily emission for two groups determined through reproductive stage emission differences. .................... 138

Figure 65. 1993 accumulated methane emissions from Sass, 1994. ........................................................................................................ 140

Figure 66. 1993 total seasonal emission with 95% confidence intervals. ......................................................................................... 142
Figure 67. 1993 and 1994 total aboveground vegetative biomass for ten mature varieties (1994 data: Huang, Y., 1994, unpublished). ....................................................... 146

Figure 68. Comparison of 1993 and 1994 methane emissions from pd to heading among ten varieties. ................................. 149

Figure 69. ........................................................................................................... 155

69a. Aboveground live vegetative biomass and methane emission for Jasmine to 73 days past flood.

69b. Aboveground live vegetative biomass and methane emission for Jasmine to 51 and 73 days past flood.

Figure 70. ........................................................................................................... 156

70a. Aboveground live biomass and emission for Lebonnet to 63 days past flood.

70b. Aboveground live biomass and emission for Lemont to 63 days past flood.

Figure 71. ........................................................................................................... 157

71a. Aboveground live biomass and emission for Dawn to 63 days past flood.

71b. Aboveground live biomass and emission for Katy to 63 days past flood.

Figure 72. ........................................................................................................... 158

72a. Aboveground live biomass and emission for Della to 63 days past flood.

72b. Aboveground live biomass and emission for IR36 to 63 days past flood.
Figure 73. .................................................................................................................. 159
    73a. Aboveground live biomass and emission for Mars to 63 days past flood.
    73b. Aboveground live biomass and emission for Brazos to 63 days past flood.

Figure 74. .................................................................................................................. 160
    74a. Aboveground live biomass and emission for Labelle to 63 days past flood.
    74b. Aboveground live biomass and emission for Jasmine to 63 days past flood.

Figure 75. 1993 and 1994 aboveground live vegetative biomass and daily emission to panicle differentiation (1994 data: Huang, Y., unpublished). .............................................................. 165

Figure 76. 1993 and 1994 aboveground live vegetative biomass and daily emission to panicle differentiation (1994 data: Huang, Y., unpublished). .............................................................. 166

Figure 77. 1993 and 1994 aboveground live vegetative biomass (greater than 200 g m⁻²) and daily emission to panicle differentiation (1994 data: Huang, Y., unpublished). ............................... 167
Figure 78. 1993 and 1994 aboveground live vegetative biomass and daily emission at panicle differentiation (1994 data: Huang, Y., unpublished). .......................................................... 169

Figure 79. 1993 and 1994 aboveground live vegetative biomass and daily emission from panicle differentiation to heading (1994 data: Huang, Y., unpublished). .......................................................... 171

Figure 80. 1993 and 1994 aboveground live vegetative biomass and daily emission from heading to filling for ten cultivars (1994 data: Huang, Y., unpublished). ............................................. 173

Figure 81. 1993 and 1994 aboveground live vegetative biomass and daily emission at filling for ten cultivars (1994 data: Huang, Y., unpublished). ......................... 174

Figure 82. ................................................................................................................. 178

82a. Panicle biomass at 73 days past flood and grain yield.

82b. Panicle biomass at 73 days past flood and grain yield (excluding IR36).

Figure 83. Harvest index for ten cultivars............................................................... 179

Figure 84. Grain yield per gram aboveground live vegetative biomass and daily emission per gram aboveground live vegetative biomass at filling................................. 181
Figure 85. ........................................................................................................... 182

85a. Grain yield and daily emission per gram
    aboveground live vegetative biomass at filling. ...................... 185

85b. Grain yield and daily emission per gram
    aboveground live vegetative biomass at filling
    (excluding IR36). ...................................................................................... 182

Figure 86. 1993 and 1994 grain yield and daily emission per
gram aboveground live vegetative biomass at filling
(1994 biomass data: Huang, Y., 1994,
unpublished). .................................................................................................. 185

Figure 87. ........................................................................................................... 187

87a. Root porosity and daily emission on heading.

87b. Aboveground live vegetative biomass and root
    porosity on heading.

Figure 88. ........................................................................................................... 188

88a. Relative chlorophyll and daily emission on heading.

88b. Relative chlorophyll and aboveground live
    vegetative biomass on heading.
1. INTRODUCTION

Methane is a radiatively active atmospheric trace gas as well as an important greenhouse gas associated with potential global warming. The total source strength of methane is estimated to be 500 Tg y\(^{-1}\), including approximately 10% due to flooded rice fields. With 460 Tg y\(^{-1}\) lost to a variety of sinks, the net annual flux of methane, equaling 40 Tg y\(^{-1}\), is currently increasing atmospheric concentrations at an annual rate of 0.5%. (Cicerone and Oremland, 1988; Neue, 1993; Steele et al., 1992).

Pressure to increase rice production worldwide is increasing along with world population. Annual world rice production must rise by approximately 47%, from 518 million tons in 1990 to 760 million tons in 2020, simply to maintain present nutrition levels (IRRI, 1989). Flooded rice paddies, producing 95% of the primary food source for more than half of the people on Earth, are a significant source of atmospheric methane (IRRI, 1991, 1989).

Due to a lack of additional arable wetlands, increased rice production will be derived from the land currently under cultivation by intensifying farming practices, multiple cropping or increasing yields with new high-yielding varieties. It has been suggested that cultivation changes which increase the number of rice crops per season will likely result in increased emission (Sass et al., 1991). Minimal experimental evidence exists upon which to predict the
potential effects of varietal differences on methane emission. With over 80,000 cultivars available throughout the world, cultivar choice represents an important and feasible candidate for the reduction of global methane flux. (Sass et al., 1991).

1.1 Methane and Rice Cultivation.

Methane is produced by anaerobic microorganisms as the last step in a series of metabolic reactions by soil bacteria that breakdown organic material originating in the soil, rice plants and floodwater. Larger plant polymers, such as cellulose and hemicellulose, are typically hydrolyzed into simpler compounds which may be metabolized through fermentation processes by a variety of bacteria. Methane producing bacteria, through syntrophic relationships with other microorganisms, are dependent on prior decomposition of these complex substrates and utilize terminal fermentation products, ethanol, acetate, hydrogen and carbon dioxide, as their metabolic substrates.

Methanogens function at near neutral pH of 6-8. The soil redox potential required for methane production has been reported at a variety of values ranging from 200-220 mV to less than -250 mV (Brock, et al., 1994; Glinski and Stepniewski, 1983; Kludze et al., 1993). When methanogenesis occurs at higher Eh levels, it probably occurs much more slowly or in isolated anaerobic microzones in which a lower redox potential is established. Soil redox potential may
be a factor in determining the rate of methane production in rice fields (Klundze et al., 1993). The reactions producing methane in rice fields involve the transmethylation of acetate and, to a lesser extent, carbon dioxide reduction (Takai, 1970).

While rice plants are not directly involved in the production of methane, they affect methanogenesis, methane oxidation and emission through close associations with soil bacteria. Numerous field studies document methane flux over rice fields in the United States, Spain, Italy, China and Japan. The effect of rice plants, though highly variable, has been found to increase methane emissions several-fold (Cicerone and Shetter, 1981; Holzapfel-Pschorr et al., 1986; Sass et al., 1989; Schutz et al., 1990; Seiler et al, 1984, Yagi and Minami, 1990). Primary productivity, plant development and stand density of rice plants influence methanogenic processes by providing pathways in which methane and oxygen can be exchanged between the submerged sediments and the atmosphere and also through the temporal and spatial availability of substrates, including root exudates and detrital matter.

1.2 Rice Plant Morphology and Life History

Distinct plant morphologies occur during the development of rice which often coincide with less apparent physiological changes. Important tissues and characteristic forms of major organs develop in an established sequence during the 60 to 120 days required for
maturation. Although climate and agricultural management practices profoundly influence the structure and growth of rice plants in complex ways, a relevant, generalized description of rice plant morphology and life history is presented below.

The growth and development of rice plants has been described by both two and three stage models (Stansel, 1975; Yoshida, 1981). Each of these models, as shown in Figure 1, is characterized by distinct and sequential events which occur during a typical time span. In the two stage model, the first period of growth is called the vegetative stage and the second is the reproductive. In the three stage model, the reproductive period ends with heading and is followed by the ripening stage (Yoshida, 1981). The three stage model is often more useful when considering the relationship between rice plants and methane emission (Figure 1).

The vegetative stage is a period in which growth is directed toward increasing the plant leaf area available to receive light and, thus, enhance photosynthetic capability. The vegetative stage lasts from germination to panicle initiation, up to one-half of the plant life span. Germination marks the beginning of growth from the seed and panicle initiation is the time at which the culm, or inner, jointed, hollow stem, first develops buds.

Panicle initiation (PI) is only observable through a microscope. Panicle differentiation (PD), which occurs approximately three to five
Figure 1. Three and Two Phase Model of Rice Plant Development. (Yoshida, 1981)
day later, is a more practical gauge of plant development. At panicle differentiation, the developing panicle, or inflorescence, is about 2 mm long and can be seen with an unaided eye (Stansel, 1975). When 30% of the main culms sampled in a rice field have panicles this size, the field is considered to be ending the vegetative stage and beginning the reproductive.

During the vegetative stage, the plant produces emergent leaves at regular intervals, increases in height and actively tillers. Erect leaves emerge individually and sequentially and, consequently, the rice plant grows taller. The primary function of the leaves is photosynthesis, though they accumulate very little of the photosynthate. The sink to which leaves transport assimilates appears to be determined by distance between the leaf and sink. Upper leaves export assimilates upward to the panicle and lower leaves support root activity by transporting assimilates downward. (Yoshida, 1981) This relationship can change, however, in response the health and requirements of the plant (King, et al., 1967; Rawson and Hofstra, 1969).

Rice leaves are supported at their base by leaf sheaths which, in turn, are joined to the culm at a node, or joint. The leaf sheaths protect pre-emergent parts of the shoot by wrapping around them and enclosing them in a cylinder. This also provides support for the entire plant. Though the leaf sheath contributes little toward photosynthesis, it stores carbohydrates prior to heading and contains aerenchyma
through which methane is transported and possibly released into the atmosphere (Nouchi, 1990).

In addition to increasing leaves and height, the vegetative stage is also the time during which the plant produces tillers. A tiller is a vegetative branch which usually includes leaves, culm and roots. Tillers emerge from leaf axils at unelongated nodes on the main culm or other tillers. A tiller and/or roots emerge at a node concurrently with the emergence of a leaf three joints above it. For example, when the fifth leaf emerges, a tiller and roots begin to emerge from the second node. The number of tillers a rice plant produces is affected by genetic factors, sunlight, plant vigor, planting density and floodwater depth (Stansel, 1975). Planting density, and the resulting competition between plants, is a significant factor on tillering rates. Usually, maximum tiller number is attained at panicle initiation, with the total number of tillers declining thereafter. A tiller may or may not produce a panicle, and ultimately, grain.

Root development during the vegetative period occurs in two forms. Other forms may arise under special conditions. A radicle, or primary root, arises from the seed, growing downward, and functions until the emergence of the seventh leaf. Nodal, or adventitious roots, appear near the soil surface with the emergence of the fifth leaf, growing laterally, and are the major component of the rice root system for most of the plant life span. Younger roots are more effective at oxidizing activity and older roots function primarily in absorption of nutrients.
During the vegetative stage, temperature and oxygen availability are critical to seedling germination, survival and growth. These factors will affect the ultimate yield of the rice crop. Rice plants, at this time, are relatively photo-insensitive, except when conditions are cloudy and cool. For most varieties, leaf senescence actually begins during this period as the first leaves begin to die, along with the radical, when the seventh to eighth leaves emerge. In dry seeded rice, irrigated rice paddies are usually flooded 30 days after seedlings emerge, or shortly after the time adventitious roots develop, although this varies with climate and cultivar.

Varietal differences in maturation time are primarily due to differences in the length of their respective vegetative stages (Figure 2). The lengths of the reproductive and ripening stages are fairly consistent among most cultivars (Yoshida, 1981). Normally, the end of the vegetative stage, determined by panicle initiation, coincides with maximum tiller number and termination of tillering activity. When a cultivar is characterized as early-maturing, it experiences panicle initiation (PI) before tillering has ended and, thus, has a very short vegetative stage. This appears as Type A in Figure 2. Late-maturing varieties, Type C, may finish tillering long before panicle initiation and, thus, have an extended vegetation period.

The reproductive stage, which lasts approximately 22 to 28 days (Stansel, 1975) or up to 30 days (Yoshida, 1981) for all rice cultivars, is the time during which plant growth is directed toward the production of the panicle and pollination of the flowers located on the
Figure 2: Rice Plant Growth Types. (Yoshida, 1981)
inflorescence. This period of intense panicle growth and high energy demand, occurring between panicle differentiation and panicle emergence represents the time of maximum vulnerability to environmental stresses for the rice plant (Stansel, 1975). The major events of the reproductive period are: elongating of the culm and increasing plant height, decreasing tiller number, emerging of the flag leaf, heading and flowering (Yoshida, 1981). Heading, and thus the end of the reproductive period, occurs when the panicle emerges; the rice field is considered to be headed when when approximately 50% of the panicles have appeared (Stansel, 1975).

During the reproductive stage, vegetative growth is completed. Leaf emergence terminates with the appearance of the flag leaf, the leaf blade immediately below the panicle, and the plant exhibits maximum leaf area near heading (Yoshida, 1981). As the final leaves are emerging, the culm elongates and the internodal distances increase, causing the panicle to boot, or move upwards inside the leaf sheaths.

Anthesis, or flowering, occurs during and after the time the panicle is emerging on an individual plant. The flower, which is part of a larger unit called a spikelet, is located at the ends of panicle branches. After a floret opens and releases its pollen, it closes and will not open again (Stansel, 1975). Usually, flowering occurs from 9:00 am to 1:00 pm and a floret is open for less than two hours (Laude and Stansel, 1927). Rice is a self-pollenating plant and if pollination does not occurs, grain is not produced (Stansel, 1974).
During the reproductive stage, it is crucial that rice plants receive adequate water and sunlight. If plants are moisture stressed during panicle differentiation or anthesis, yield reduction may occur (Stansel, 1975). Also, there is a critical sunlight-requiring period, beginning at panicle differentiation and lasting until about ten days prior to maturity, during which the rice plant must receive sufficient sunlight or yield reduction may result due lowered photosynthesis (Stansel, 1975, Sass et al., 1991b). The yield of the rice crop is extremely vulnerable during the reproductive period because plant growth conditions at panicle differentiation can affect the number of florets that form on a panicle and also because the photosynthetic activity of a rice plant during this time is so closely coupled to later grain filling.

Ripening, the final stage of development of the rice plant, begins at heading and ends when the average moisture of the grain in the field is 21% (Stansel, 1975). The duration of the ripening stage is approximately 30 days (Yoshida, 1981) and may extend to 42 days under cooler weather conditions (Stansel, 1975). During this time, the primary function of rice plant activity is grain filling, although grain yield of the rice crop can be affected by events occurring in any of the three stages (Stansel, 1975). This period is characterized by the increasing size and weight of grain, color changes of grain and leaf senescence (Yoshida, 1981).

The developing grain changes in color and texture as it increases in weight. In the early ripening stage, the immature grains
are green and milky. As they fill and mature, the grains turn yellow and change to a semi-solid and then solid state (Yoshida, 1981). The grain proceeds through the following series of developmental stages based upon these changes: milky, dough, yellow ripe and mature (Yoshida, 1981). The increase in grain size and weight is due to the amount of accumulated carbohydrate that is translocated to the grain from other temporary storage sites.

Carbohydrates, stored as starch in the culm and leaf sheaths before heading, are transported in the form of sucrose to the grain during ripening in order to fill the grain. In addition, the photosynthetic activity of the upper leaves remains very high at this time and contributes to grain filling (Stansel, 1975; Yoshida, 1981). If weather conditions consist of low light conditions, then the carbohydrate supply available for grain filling is reduced and crop yield is diminished (Stansel, 1975).

As carbohydrate, in a milky, watery form, is translocated from other plant organs to the grain, the lower leaves of the rice plant begin to senescence at a rapid rate. Leaf senescence advances up the plant toward the upper leaves as the ripening stage progresses (Yoshida, 1981; Stansel, 1975). The rate of leaf senescence is related to grain filling in a complex way (Yoshida, 1981). In some cases, faster leaf senescence is coupled to more rapid translocation; this may be a factor in faster grain-filling. At other times, rapid leaf senescence is associated with poor weather conditions (Yoshida, 1981).
1.3 Plant Development, Biomass and Methane Emission

The seasonal patterns of methane emission are intimately tied to the growth and death of rice plants. Net primary productivity, the total amount of carbon fixed by a plant after respiration, can be determined as the average plant biomass produced per day during the season. An allometric, or relative growth, relationship exist between rice roots and the total plant; consequently, an approximately constant proportionality is maintained between total and belowground biomass during most of the life of the plant (Yoshida, 1981). The growth of live aboveground biomass in rice fields, and generally in all natural wetland systems, is closely related to live belowground biomass (Gross et al., 1993).

Strong correlations have consistently been obtained with biomass and methane production and emission measurements (Gross, et al., 1993; Sass, et al., 1990, 1991; Whiting and Chanton, 1993). These correlations, which occur using aboveground, belowground and total biomass data, suggest that the processes of methane production and emission are closely coupled with, though not completely explained by, the primary productivity of plants. The consistency of the relationship between methane emission and biomass was recently reinforced by data from a diverse group of wetland communities that included swamps, subtropical marshes, subarctic peatlands and agricultural rice fields. Although these data were collected only once at each site, the net ecosystem productivity, when calculated as net
primary production minus soil and microbial respiration, strongly correlated with methane flux (Whiting and Chanton, 1993). From these data, the researchers proposed that net ecosystem productivity is a "master variable" that integrates a variety of parameters, such as photosynthesis, exudation, oxidation and gas transport, which determine methane emission in wetlands.

Results from several studies suggest that rice plants help determine seasonal methane emission patterns observed in rice fields. Seasonally, two to three methane maxima were observed in Italy (Holzapfel-Pschorr, et al., 1986; Schütz et al., 1989), Texas (Sass, et al., 1990, 1991a) and Japan (Yagi and Minami, 1990). The first peak was related to degradation of soil organic matter early in the vegetative phase of rice growth (Holzapfel-Pschorr et al, 1986; Schutz et al., 1991a) The second peak, observed approximately two to three weeks later, was associated with accelerated plant growth during the late vegetative and reproductive stages of plant development. The increased release of root exudates or rate of root autolysis at this time may be a factor in the elevated emission levels (Holzapfel-Pschorr et al, 1986). It was suggested that the third peak in methane emissions was related to plant senescence and increases in dead biomass during the ripening stage (Schutz, et al., 1991). In Texas, only the second and third peaks were observed without incorporated straw (Sass et al., 1990).
1.4 Aerenchyma Tissue and Methane Emission

In response to the anaerobiosis created at flooding, rice plants and other wetland species develop or enhance aerenchymal tissue, specialized gas transport tissue, which is independent of transpiration and gas movement through stomata. (Armstrong, 1978; Neue, 1993; Nouchi, 1990). Aerenchyma is tissue containing intercellular air spaces, or lacunae, which is formed either by the collapse of cells (lysigeny) or by cell separation with no collapse (schizogeny) (Laan et al., 1989). Its formation is initiated by the presence of ethylene during oxygen deficient conditions (Kawase, 1981). In addition to environmental factors which contribute to intercellular air spaces, aerenchyma development is also dependent upon genetic characteristics of the plant (Yoshida, 1981).

The primary purpose of aerenchyma tissue is the movement of atmospheric oxygen to the rhizosphere (Chanton and Dacey, 1991). This oxygen is available for aerobic respiration by the roots and for the oxidation and immobilization of potentially phytotoxic materials such as Fe$^{+2}$ and Mn$^{+2}$ (Armstrong and Armstrong, 1988). As these air spaces provide a pathway for oxygen transport into submerged roots, they also allow the movement of methane out of flooded sediments and into the atmosphere (Figure 3). Aerenchyma affects the emission of methane two ways by: (1) facilitating the flow of methane from flooded soils, through the plant and out via micropores in the leaf sheaths and (2) regulating the methane producing and
Figure 3. Methane Production, Emission and Oxidation Associated with Rice Plants (Schutz et al., 1991)
oxidizing capability of the rhizosphere by maintainance of the oxygen supply to the roots (Kludze et al., 1993; Nouchi, 1990, Schutz et al., 1991).

The formation of aerenchyma in waterlogged plants may be initiated by the presence of ethylene which leads to increased cellulase activity (Kawase, 1968; Jackson, 1990). Ethylene is a phytohormone active in fruit ripening and leaf and flower senscence. The localized application of ethylene to plant stems was shown to significantly increase the level of cellulase activity (Kawase, 1981). The plant enzyme, cellulase, is responsible for the breakdown of cell walls and contributes to the formation of lysigenous intercellular air spaces.

The effects of rice plant aerenchyma on methane emission, inhibition and oxidation have been investigated in recent research. It has been estimated that up to 70% of the methane emitted from undisturbed rice fields was through aerenchyma of the rice plant (Neue, 1993). Early season, or vegetative stage, data suggested that ebullition was the primary mechanism for methane movement from flooded soils. Although data collected during the rice plant's reproductive phase indicated that approximately 90% of the methane flux was supported by the aerenchyma tissue, the mechanism involved in methane emission at this time remains unresolved (Holzapfel-Pschorr et al., 1986; Schutz et al., 1989b; Fisher, personal communication). Planting density may also influence emission rates through effects of the aerenchyma tissue. It was reported that methane
emitted from a rice field planted at one-third the standard density was 30% less than normal flux values (Schutz et al., 1989a).

In addition to methane transport out of the plant, aerenchyma tissue moves oxygen into the rhizosphere. The oxygen is then available to inhibit methane production or to oxidize between 50 and 80% of the methane that is produced in anoxic soils before it reaches the atmosphere (Holzapfel-Pschorr et al., 1986; Sass et al., 1991). One recent laboratory study, testing the effect of soil redox potential on methane emissions in rice plants, concluded that differences in methane production rates due to Eh changes influenced emission rates more than differences in root porosity, or air space, of the plants (Klundze et al., 1993). The dynamics of methane inhibition, oxidation and emission by vegetation are complex and need continued investigation.

1.5 Exudation, Senescence and Methane Emission

The growth and development of rice plants augment existing pools of organic carbon in the soil through the processes of root exudation and plant senescence. Sources of existing carbon include straw and manure added before planting. The organic carbon in the soil provides substrates for bacteria and can result in increased methane production and emission.

Roots release organic matter into the soil through natural growth processes, by interactions with microorganisms or soil particles
and during periods of anaerobiosis. Exudates are water-soluble, diffusible compounds that leak from roots (Martin, 1977b). Other materials, such as mucigel, cell wall fragments and entire cells are also released by the roots. The primary area affected by the leakage of exudates and other materials is the rhizosphere, the 1-2 mm zone around the root surface in which the root interacts with its environment. Suggested functions of the exudates released during growth are: (1) the improvement of nutrient availability and uptake from the soil through chelation or reduction of compounds such as Fe, Mn and phosphate, (2) the removal of toxic substances from plant cells, (3) the reduction of spatial competition with other plant species and (4) the development of mucilage at the root tip (Marschner, 1985). Root exudation, within anaerobic sites in the rhizosphere, stimulated methane emission in laboratory experiments with rice seedlings (Raimbault et al., 1977).

The primary source for exudates is the point of emergence of lateral root tips and not the cells and tissues of older roots (McDougall and Rovira, 1970). These exudates may result from injury associated with the mechanical aspects of lateral root growth or they may simply be leaked from the new root apices (Ayers and Thornton, 1968; McDougall and Rovira, 1970). Results from two recent field studies, one in Italy and one in China, found that methane emissions were most enhanced by rice growth during the reproductive stage (Holzapfel-Pschorr et al., 1986; Wang et al., 1990). The reproductive stage, which starts at panicle initiation and ends at heading, is the time
of highest physiological activity, maximum nitrogen uptake from the soil and establishment of reduced conditions in the rhizosphere (Yoshida, 1981).

Adaptation to flooded conditions varies within and among plant species. Within species, differential adaptation to flooded conditions among two varieties of *Veronica peregrina*, interpreted as the capacity to accumulate malate, was observed in California (Linhart and Baker, 1973). Differences among species were observed in early studies of seeds (Crawford, 1978). The seeds of flood-adapted species, including rice, did not show the increased glycolysis or ethanol accumulation under anoxic conditions that is seen with flood-intolerant species. The tissue of flood-intolerant plants was damaged by the ethanol that accumulated in it during anoxic conditions.

More recent experiments showed that roots of aquatic macrophytes adapted to reduced soil conditions, when compared to macrophytes adapted to oxidative sediments, exhibited increased ethanol and carbon dioxide production, higher root porosity, oxygen leakage confined to root apices and increased root vitality when both were cultured under anoxic conditions (Smits, et al., 1990). They concluded that ethanol fermentation capacity was greater in flood-tolerant species and that the effects of the accumulated ethanol were not detrimental to the plants. According to these results, the presence of ethanol should be predicted in wetland plant species during periods of submergence. The differential adaptation to flooded conditions within and among species suggested by these studies emphasizes the
importance of determining the cultivar effects on methane emission associated with rice cultivation.

In addition to root exudation processes, organic material in flooded soils increases when rice plants and other plant species in flooded rice fields senesce near the end of the growing season. Aboveground plant matter and root litter are both contributed to the pool of organic carbon in the soil as dying plant biomass increases (Schutz, et al., 1991). Deteriorating aboveground biomass of rice plants and additional floodwater biomass from algae and weeds supplement the amount of total organic carbon in the soil, though the magnitude of this contribution needs further investigation (Fisher, personal communication).

1.6 Rice Varietal Differences and Methane Emission

The significant contribution of rice cultivation to the production and emission of methane emphasizes the importance of determining the effects of varietal differences on these processes. During the first half of the growing season, plant productivity, due to its association with exudation and sloughing from roots, may be an important potential plant factor affecting methane emission. Therefore, variation in biomass production among cultivars may significantly affect emissions from cultivars. Varietal differences in the development of aerenchyma tissue and rate of senescence may also result in emission differences among cultivars.
Although the genetic basis for morphological and physiological inter-population differences within wetland species is well accepted, few studies have been conducted to investigate methane emission differences among cultivars. Most reported effects of rice plants on seasonal methane emission patterns are based on studies involving comparisons of rice field emission with emission from unvegetated control plots or studies of emission differences due to plant responses to soil types, fertilizer and water factors or climatic conditions. These experimental designs provide little basis for hypotheses about the plant mechanisms through which these effects are accomplished.

Two recent studies, one near Beijing, China, and another in India, indicated that rice varieties differed in associated methane emission by as much as a factor of two and ten, respectively (Erda, 1993; Parashar, et al., 1991). However, neither study investigated specific plant parameters as independent variables affecting methane emission rates. Experiments involving rice cultivars with distinct morphologies and physiologies appear to be a critical and presently unavailable source of data that is crucial to our understanding of the role rice plants have in observed methane emission patterns and their potential for mitigation.
2. FIELD DESCRIPTION AND METHODS

2.1 Field Description and Management

All field experiments were conducted at the Texas A&M University Agricultural Research and Extension Center. The Extension Center is located near Beaumont, Texas, at longitude 94°30'W, latitude 29°57'N. It supports a 17-county area in the Texas Coastal Prairie which produces more than 25% of the rice grown in the United States. The annual growing season at this location is approximately 275 days and, on average, temperatures below 0°C are experienced only 15 days per year. About 50% of the 1340 mm average rainfall occurs during the rice growing season of April through September.

Ten contiguous plots, approximately 5.5 m x 30 m, were chosen and prepared for the cultivars (Figure 4). The soil in the plots, Lake Charles clay, was classified as a Typic Pelludert and exhibited poor internal and surface drainage. On the average, sand, clay and silt were present in the ratio, 21%:37%:42%. As shown in Table 1, the soil composition of the ten fields was reasonably homogeneous. On the average, nitrogen, hydrogen and carbon were present, by weight, at 0.11%, 0.95%, 1.6%, respectively. The average ratio of total organic carbon to total carbon was 0.85, with no observed difference among plots, although the plot containing Jasmine was planted in rice the
Table 1. Lake Charles Soil Analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Nitrogen</th>
<th>Hydrogen</th>
<th>Total Carbon (TC)</th>
<th>Total Organic Carbon (TOC)</th>
<th>TOC:TC</th>
<th>Sand</th>
<th>Clay</th>
<th>Silt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (%wt)</td>
<td>0.11</td>
<td>0.95</td>
<td>1.60</td>
<td>1.36</td>
<td>0.85</td>
<td>36.83</td>
<td>21.22</td>
<td>42.04</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.01</td>
<td>0.02</td>
<td>0.14</td>
<td>0.19</td>
<td>0.08</td>
<td>0.89</td>
<td>1.06</td>
<td>0.64</td>
</tr>
</tbody>
</table>
previous year. A slight sand gradient existed across the experimental site with the higher concentrations at the south end. Soil in the plots with Labelle and Jasmine had a significantly lower sand content (18.78%) than did the other fields (21.63%). The clay content also varied from a low of 35.54% in the plots containing Lebonnet and Lemont to 38.14% in those with Labelle and Jasmine. The difference in the sand/clay content of the soil has been shown to affect methane emission, though probably not to the levels observed in this experiment (Wang, et al., 1993; Sass, et al., 1994).

The schedule of field events is shown in Table 2. On April 27, 1993, the fields were drill-planted by machine in rows on 20 cm centers with a seeding rate of 112.1 kg ha\(^{-1}\). The rice plants emerged within 12 days and most varieties were flooded 35 days after emergence, June 7, 1993. Nitrogen fertilizer, as urea, and phosphorus were applied at planting (56.05 kg ha\(^{-1}\) each), before flooding, June 7, 1993 (51.12 kg ha\(^{-1}\) and 63.9 kg ha\(^{-1}\), respectively) and between June 27 and July 13, 1993, at panicle differentiation for each cultivar (44.84 ha\(^{-1}\), nitrogen only). Two herbicides, Propanil and Bolero, were applied on May 14, 1993 (3.36 kg ha\(^{-1}\) and 2.24 kg ha\(^{-1}\)) and a second application of herbicide occurred a week later using Propanil and Basagran (3.36 kg ha\(^{-1}\) and 1.68 kg ha\(^{-1}\)). Irrigation water was obtained from a surface canal system and was used to flood fields at 47 days after planting. Thereafter, a 8-15 cm flood was maintained until the rice matured. Biomass was sampled eight times during the growing season on the dates indicated in Table 2. Nine of the ten
Table 2. 1993 Field Management and Plant Development

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
</table>
| April | 27 Plant  
      |       | Additions: Nitrogen (56.05 kg ha⁻¹), |
|       |       | Phosphorus (56.05 kg ha⁻¹)          |
| May   | 7     | Emergence, start                    |
| May   | 9     | Emergence, end                      |
| May   | 14    | Application: Propanil (3.36 kg ha⁻¹), |
|       |       | Bolero (2.24 kg ha⁻¹)               |
| May   | 22    | Application: Propanil (3.36 kg ha⁻¹), |
|       |       | Basagran (1.68 kg ha⁻¹)             |
| May   | 26    | Additions: Nitrogen (51.12 kg ha⁻¹), |
|       |       | Phosphorus (63.90 kg ha⁻¹)          |
| June  | 7     | Permanent Flood                     |
| June  | 23    | Begin Flux Samples, Biomass Sample 1 |
| June  | 27    | Panicle Differentiation, start       |
| June  | 29    | Addition: Nitrogen (44.84 kg ha⁻¹)* |
| July  | 7     | Biomass Sample 2                    |
| July  | 9     | Biomass Sample 3                    |
| July  | 13    | Panicle Differentiation, end        |
| July  | 16    | Heading, start                      |
| July  | 20    | Biomass Sample 4                    |
| July  | 28    | Biomass Sample 5                    |
| August| 3     | Heading, end                        |
| August| 9     | Biomass Sample 6                    |
| August| 16    | Biomass Sample 7                    |
| August| 17    | Harvest, start                      |
| August| 19    | Biomass Sample 8                    |
| August| 20    | Drain*                             |
| September | 2  | Drain (Jasmine)                     |
| September | 15 | Harvest, end                        |

* (excluding Jasmine)
varieties were drained 74 days after flooding on August 20, 1993; Jasmine was drained on September 2, 1993. The rice was harvested between August 17 and September 15, 1993.

2.2 Field Parameters

The air and water temperature and water depth were recorded at the time of biomass sampling. Air temperature was measured approximately 1 meter above the boardwalk in the center of the research site. Water temperature was measured approximately 2 cm below the surface of the water in the each field. Water depth in each field was also measured at this time by lowering a meter stick into the flood water until it rested perpendicularly on the surface of the submerged soil. Water temperature and water depth measurements were consistently taken in each field at a location adjacent to the northern end of the eastern boardwalk. These measurements were combined with equivalent measurements made by staff at the A&M Extension Center during methane flux sampling (see Related Research).

2.3 Cultivars

The cultivars chosen for this study were similar in the length of their growing season and their growth requirements. The following ten, locally-grown varieties were planted: Lebonnet, Lemont, Dawn,
Katy, Della, IR36, Mars, Brazos, Labelle and Jasmine. This group contains rice cultivars with a variety of structural, resistance and yield characteristics (Table 3).

All experimental cultivars, with the exception of Labelle and Jasmine, were classified as early-maturing. Only one semi-dwarf variety, Lemont, was included with eight varieties considered to be conventional type. Traits for which the cultivars showed the greatest variability were oxygen leakage and straighthead resistance.

The experimental plant characteristics of oxygen leakage and straighthead resistance are thought to be related through their relationship to the oxygen conditions of the soil. Oxygen leakage is a plant trait determined under laboratory conditions as the level of oxygen diffusing from the root tips of rice seedlings. Straighthead is physiological, nonparasitic disease of rice which results in yield loss. The condition can be controlled by flood drain, or soil aeration, when it occurs (Stansel, 1975). Four of the cultivars in the study, Dawn, Katy, Della and Mars, were characterized as having low oxygen leakage and average to moderate susceptibility to straighthead. There were three cultivars rated as having high oxygen leakage from roots, Lemont, Brazos and Jasmine, and the resistance to straighthead of these cultivars was moderately resistant, resistant and very susceptible, respectively.
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Character</th>
<th>Type</th>
<th>Height (cm)</th>
<th>Grain Character</th>
<th>Oxygen Leakage</th>
<th>Resistance</th>
<th>Yield Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebanon</td>
<td>E</td>
<td>C</td>
<td>126-130</td>
<td>L</td>
<td>M</td>
<td>R</td>
<td>M</td>
</tr>
<tr>
<td>Lemont</td>
<td>E</td>
<td>SD</td>
<td>125-130</td>
<td>L</td>
<td>H</td>
<td>MR</td>
<td>H</td>
</tr>
<tr>
<td>Dawn</td>
<td>E</td>
<td>C</td>
<td>126</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>S</td>
</tr>
<tr>
<td>Kay</td>
<td>E</td>
<td>C</td>
<td>119-120</td>
<td>L</td>
<td>L</td>
<td>MS</td>
<td>H</td>
</tr>
<tr>
<td>Delia</td>
<td>E</td>
<td>C</td>
<td>130-132</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>H</td>
</tr>
<tr>
<td>IR36</td>
<td>E</td>
<td>NA</td>
<td>118-120</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mars</td>
<td>E</td>
<td>C</td>
<td>130-132</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>NA</td>
</tr>
<tr>
<td>Brazos</td>
<td>E</td>
<td>C</td>
<td>133-137</td>
<td>C</td>
<td>115-120</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Labesse</td>
<td>E</td>
<td>VE</td>
<td>114-116</td>
<td>C</td>
<td>122-123</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>Jasmine</td>
<td>A-L</td>
<td>140</td>
<td>97-106</td>
<td>C</td>
<td>L</td>
<td>H</td>
<td>VS</td>
</tr>
</tbody>
</table>

*E=Early, VE=Very Early, A=Average, LA=Late, C=Conventional, SD=Semi-Dwarf, M=Medium, L=Long, M=Medium, MR=Moderately Resistant, VS=Very Susceptible, R=Resistant, NA=Not Available
2.4 Determination of Tiller Number

Due to the heterogeneity of plant density, primarily related to germination, and also to the relatively small size of the biomass sampling frame (described below), a separate determination of tiller number for scaling purposes was made. The number of tillers per 0.25 m\(^2\) for each cultivar was obtained by three different methods. At the time biomass samples 1, 2, and 4 were collected, a 0.5 x 0.5 m quadrat frame was randomly placed in each field and the tillers within the perimeter of the frame were counted. This procedure was repeated three times for each field and the average tiller number was calculated. It was determined that many small tillers below the floodwater remained uncounted with this method and there was large variation among some replicate tiller counts.

The tiller numbers for biomass samples 3, 5 and 8, which consisted of 0.5 x 0.5 m of clipped aboveground biomass only, were determined by counting the total number of tillers included in the sample. This was done in the laboratory before sorting and drying. The tiller count in the sample was used for analysis, instead of an average, due to method of collection.

For all cultivars, biomass samples 6 and 7 were collected after heading, a time when tiller number is reported to be constant, on August 9 and August 16, respectively. Since the variation associated with tiller counts obtained in the field with biomass samples 1, 2 and 4 was large, the tiller counts of samples 6 and 7 were calculated as the
average of the tiller counts obtained when tiller numbers became consistent. For most varieties, this was the average tiller number from biomass samples 3, 4, 5 and 8.

Before the biomass measurements were converted to mass per square meter, all categories of biomass per tiller were found within each sample. The measurements for biomass samples 1, 2, 4, 6, and 7, collected with the 0.2 x 0.2 m metal sampling frame, were scaled to 0.25 m² using the number of tillers counted or calculated in 0.25 m² (biomass stem⁻¹ * stems 0.25 m⁻²). Biomass (0.25 m²) was then converted to biomass per square meter by multiplying with the area value [sample biomass (0.25 m²) * 4]. This conversion method, corrected for row number (biomass 0.25m⁻² * 0.83), was used to convert all biomass measurements to the scale of a square meter.

2.5 Biomass Measurement

Biomass was determined in order to examine seasonal biomass partitioning processes within and among cultivars and to determine differences in total biomass production among the varieties. Total aboveground biomass was determined eight times during the season and total belowground biomass was measured five times. Two samples were obtained at each of these collection periods. Plant height was also determined at this time.

For each variety, the heights of three to five plants were measured and the average height was found. Plant height was
determined as the vertical distance from the stem-soil interface to the tip of the last leaf on the stem. Increase in height is primarily the result of leaf emergence during the vegetative stage and leaf emergence plus internode elongation during the reproductive stage. The maximum plant height is attained and maintained during the ripening stage and was determined as the vertical distance from the stem-soil interface to the tip of the flag leaf.

Biomass was collected using three methods (Table 2). In the first procedure, used in biomass samples 1, 2 and 4, two 0.2 x 0.2 m metal sampling frames, designed by Dr. Frank Fisher and Cylette Willis, were placed randomly over two rows of rice and then driven 0.1 m into the submerged soil using a pounding device designed by Dr. Fisher. The number of tillers within a frame was counted for each sample. After the frames were removed and cleaned, the roots in the first sample were cut to a 5 cm depth and the roots in the second sample were cut to a 10 cm depth. The aboveground biomass was divided into stems and leaves, panicles, crowns and dead plant material.

In determining belowground biomass, the soil was rinsed from the roots and then the roots were separated from the crown for drying. Belowground biomass was not sorted into live and dead biomass due to the difficulty and potential inaccuracy involved in the discrimination between the two. The root biomass at 5-10 cm was calculated as the difference between the dry weight of the 10 cm and
the 5 cm samples. After inconsistent results, the procedure was modified and data that appeared invalid were removed before analysis.

A second, or revised, method for biomass sampling was used to obtain biomass samples 6 and 7. The steps described above for the first procedure were followed through the removal and cleaning of the frames. At this point, the root biomass at 5-10 cm depth was cut and both sections from each sample were bagged. In the lab, the roots attached to the stems (0-5 cm depth) were gently rinsed over a sieve and then removed from the crown. The lower section of each sample (5-10 cm) was carefully taken from the bag and rinsed in a sieve before drying. As in the first method, the aboveground biomass was sorted into stems and leaves, panicles, crowns and dead plant material before drying. Belowground biomass was not sorted.

In the third method, a 0.5 x 0.5 m quadrat frame was randomly placed in each field and the plant material within the frame was clipped at the surface of the submerged soil. The number of tillers in each sample were counted. These samples, consisting of aboveground biomass only, were sorted into stems and leaves, panicles and dead plant material before drying. This procedure was used for biomass samples 3, 5 and 8.

For all three procedures, each category of plant biomass for each variety was placed into a separate, pre-weighed paper bag and then the biomass and bag were weighed together. Smaller bags were used for crown and root biomass than for the other categories to increase accuracy. The bags were placed into ovens and dried at
74°C. After 24 hours, the bags and contents were removed from the ovens and allowed to equilibrate with room temperature. At this time, they were weighed and then returned to the ovens. All biomass samples were dried until they reached a constant weight. Constant weight was reached when the sample weight changed less than 5% between weighings. The dry weight for each biomass sample was then calculated as the difference between the weight of the bag plus biomass and the weight of the bag.

Several biomass categories were used for analysis. Total aboveground biomass was divided into aboveground live vegetative biomass, aboveground dead vegetative biomass and panicle biomass. Aboveground live vegetative biomass included green leaves, sheaths and stems. Aboveground dead vegetative biomass consisted of leaves, sheaths and stems which were primarily brown. Total aboveground vegetative biomass was the sum of aboveground live vegetative biomass and aboveground dead vegetative biomass. Panicle biomass was considered aboveground live vegetative biomass until the panicle had completely emerged at heading and could be removed at the base of the head. Detached panicles were weighed and summed in the category, panicle weight. Total plant biomass was determined as the sum of all biomass components, aboveground live vegetative biomass, aboveground dead vegetative biomass, panicle, crown and root biomass. The crown, or tissue forming the stem-root juncture, was separated from both aboveground and belowground biomass and
weighed independently. Root biomass included both live and dead root tissue, although the weight of the dead root biomass was negligible.

Before biomass data collected using different sampling frames were pooled, the measurements were compared for consistency. Biomass samples 2 and 3 (taken 30 and 31 days past flood, respectively) and 7 and 8 (taken 70 and 73 days past flood, respectively) were used in the assessment. Comparisons of aboveground live vegetative biomass samples 2 and 3, as well as 7 and 8, are shown in Figure 5.

Samples 2 and 3 were collected during a time of early, rapid growth. All cultivars show increasing aboveground live vegetative biomass. The average percentage increase between the two collection dates was 55%, with a range of 0% to 93%. Samples 7 and 8 were taken 3 days apart during a period of accelerated senescence for most cultivars. Eight of the ten cultivars decreased or remained constant in aboveground live biomass between these two samples. The average amount of change was 14%, with a range of 0 to 33%.

2.6 Root Porosity

Root porosity was determined in order to examine (1) the seasonal development of root air space, (2) the variation in this parameter between cultivars and (3) the relationship between stem and root aerenchyma within cultivars. Porosity, expressed as the fraction of the root that is air space, characterizes the development of
aerenchyma tissue in the root and is important to the plant for internal aeration.

Porosity of rice plants roots was determined at biomass collection periods from 30 to 70 days past flooding. The plant samples, which were collected for the root observations and tiller cross-sections, also provided root material used to analyze root air space. For each cultivar, four replicate samples of root tissue were collected and measured.

Two methods were used to determine root air space for the ten rice varieties and, for both methods, the preparation of the root tissue was the same. The roots of each variety, 0-10 cm, were gently and thoroughly rinsed. They were straightened, placed horizontally on a supported paper towel and carefully blotted. Then, the roots between 2.5 and 5 cm were removed from the remaining root biomass and placed in a mortar containing deionized water. The root material in the mortar was gently cut and then mixed until it appeared uniform. This was done because the roots in the original section removed from the plant varied in age, thickness and color. The water was drained from the mortar and four samples were selected for immediate analysis.

The first method used to determine root porosity was originally described in 1969 (Jensen et al., 1969). A pre-weighed wide-mouth pycnometer was filled with deionized water at 22°C and weighed on an analytical balance ($W_W$). Each sample of root material was placed in the pycnometer bottle filled with deionized water at 22°C. The air
bubbles among the root pieces were freed and the pycnometer was carefully capped and weighed on the analytical balance \(W_{\text{r+w}}\). After this, the water was poured from the pycnometer, the roots were gently blotted, and the root sample was immediately weighed \(W_{\text{r}}\). The error due to the evaporation of water from the roots during weighing was small.

The roots were then placed in a tissue grinder and ground until they appeared homogeneous, approximately 8 minutes. The homogenate was poured from the tissue grinder into the pycnometer which was placed in an ice bath until the temperature returned to the original water temperature, 22°C. The remaining space in the pycnometer was then filled with rinse water from the tissue grinder, capped, and weighed \(W_{\text{h}}\). The root porosity was then calculated with the formula:

\[
\text{\% porosity} = 100 \frac{(W_{\text{h}}-W_{\text{r+w}})}{(W_{\text{w}}+W_{\text{r}}-W_{\text{r+w}})}.
\]

This procedure was repeated with four samples from the ten cultivars. It was used for the first root porosity analysis only.

A second procedure for determining root porosity, developed by Dr. Ronald Sass and based on modification of the first method, assumed that root tissue density in all cultivar roots was constant and that the weight of the air in the aerenchyma of roots is negligible. A constant density for cultivar root tissue, 1.04 g cm\(^{-3}\), was verified with an analysis of variance performed with samples from nine
cultivars at 30 days past flood and three cultivars at 43 days past flood. Through the revised method, root air space was calculated by relating the density of the root tissue ($D_{rm}$) to the density the roots ($D_{r+a}$).

The samples of root material were placed in the pycnometer bottle which was filled with deionized water at 22°C. As in the first method, the air bubbles among the root pieces were freed, and the pycnometer was carefully capped and weighed on the analytical balance ($W_{r+w}$). Afterward, the water was poured from the pycnometer, excess water was carefully blotted from the roots and the root sample was immediately weighed alone ($W_r$). The weight of the bottle filled with deionized water only was known ($W_w$). The root porosity was calculated with the following equations:

$$D_{r+a} = \frac{W_r}{W_w + W_r - W_{r+w}}$$

$$D_{rm} = \frac{W_r}{(W_w + W_r - W_{r+w}) - (W_h - W_{r+w})}$$

$$\text{Porosity} = \frac{(D_{rm} - D_{r+a})}{D_{rm}}$$

The revised procedure, which did not require grinding root tissue, considerably reduced the time needed to determine root porosity and may have increased the accuracy of the measurement because homogenate was not lost when being transferred from the tissue grinder to the bottle. This procedure was used in the remaining root air space analyses conducted between 43 and 70 days past flood. As
with the first method, root porosity was measured using four samples for each of the ten cultivars.

2.7 Relative Chlorophyll

Chlorophyll measurements were used for relative comparisons within and among cultivars in order to determine temporal and varietal differences during the growing season. Chlorophyll in the leaves of each cultivar was determined in the field when biomass samples were collected from 30 to 70 days past flood. Five readings were made using independent, randomly selected plants. The measurements were taken with a Minolta Chlorophyll Meter, Model Number 502, approximately 5 cm below the tip of the leaf. The chlorophyll reading made by the meter is related to the amount of chlorophyll in the leaf, although it is not a measure of chlorophyll concentration. Chlorophyll measurements made in this manner appear in the literature in units called SPADs (Fred Turner, personal communication).

2.8 Root Observations

An observational record of plant roots was maintained between 30 and 70 days past flood by making slides of cultivar samples at each biomass sampling period. The purpose of this photographic collection was to document varietal root development and any apparent
differences between cultivars. Root length, color, size and odor were examined each time photographs of the roots were taken.

In order to produce the library of photographic images, a third sample of rice plants, in addition to biomass samples, was dug from each cultivar field using a shovel. The plant samples were placed in plastic bags containing field water, stored in a shaded, insulated container and returned to the laboratory as quickly as possible. The plants were placed in a refrigerator at approximately 5°C until they could be examined. All of these precautions were taken to preserve integrity of the plant tissue.

In the laboratory, the plant roots were gently and thoroughly washed and their total length was measured. They were then lowered into a glass container, filled with deionized water, which was designed and built by Dr. Frank Fisher to support and display the roots for photography. The free-standing container, 25.8 cm X 30.9 cm X 0.2 cm, was joined at the edges with foam and silicon sealant. The container, with the plant, was placed under four 500 watt lights and a ruler was placed beside it for scale. Two color slides were made for each cultivar using Ektachrome Elite 100 slide film and a Tiffen 52 mm blue filter to correct for indoor lighting. The slides were processed by a professional lab.
2.9 Determination of Cross-Sectional Area of Aerenchyma

The development of aerenchyma in the leaf sheaths of each cultivar was documented between 30 and 70 days past flood by making slides of samples at each biomass sampling period. The purpose of this photographic collection was to determine temporal differences in the initiation of aerenchyma development between cultivars and apparent varietal variation in the extent of aerenchyma development within the tillers. Tiller diameter, color and vitality, were examined each time photographs of plant aerenchyma were taken.

Tissue from the rice plant samples collected for root observational purposes was used to examine the development of aerenchyma in leaf sheaths. The tillers were removed from the roots at the crown and gently rinsed. The cross-sections, approximately 0.3-0.5 mm thick, were cut 5 cm above the lower end of the tiller, using an Altmirko hand microtome. Two to three cross-sections were taken from one tiller and examined for quality under a light microscope. Cross-sections samples were collected from four different tillers for all cultivars,

These samples were then photographed using a Nikon F-1 camera with bellows and Technical Pan black and white slide film. A Tiffen 52 mm magenta filter was used to increase the contrast in the photographs and emphasize the air space area in the aerenchyma tissue. The slides were developed in D76 developer at 20°C for four minutes.
3. RELATED RESEARCH

3.1 Measurement of Methane Emissions

Before flooding, boardwalks were built across the east and west sides of each rectangular field, approximately 7.3 m into the paddy, in order to reduce soil disturbance during flux measurements (Figure 4). From the boardwalks in each of the eleven plots, two randomly placed aluminum flux collars were permanently installed in order to ensure reproducible placement of gas collecting chambers during methane emission measurements.

Methane flux measurements were obtained by staff of the Texas A&M Agricultural Experimental Station. The methane flux was determined by sampling the headspace gas in an open-bottom chamber with a cross-sectional area of 0.397 m$^2$ and a volume of 0.119 to 0.476 m$^3$, depending on the height of the rice plants. When the chamber was placed over the vegetation, the bottom edge of the chamber rested in a groove in the permanent collar located below the surface of the flood water. A mylar blanket or 1-cm foam insulation was placed on the chamber during measurements to reduce temperature fluctuations. Circulating fans were installed in the larger chambers to ensure complete gas mixing.

Methane emission measurements were obtained two times per week from the period the fields were permanently flooded until they
were drained for harvest. When emission measurements were taken in each field, plant height, air, soil and water temperature and water depth were also recorded.

A gas chromatograph fitted with a flame ionization detector was used to determine methane mixing ratios. A set of five 50-cm³ samples were taken over a 30-minute period and methane emission was estimated from the slope of the mixing ratio change in the set. Sample set plots of methane concentration versus time which did not attain a linear regression value of $r^2$ greater than 0.90 were rejected.

3.2 Grain Yield Determination

Staff of the Texas A&M Agricultural Experimental Station determined the appropriate time of harvest for each of the ten cultivars in the study. At this time, grain from a 5.5 m x 0.8 m section of each field was harvested by machine and the rice was collected into one sample bag and, from this, four replicates were prepared.

The grain was oven dried to approximately 14% moisture and then the actual moisture content of the rice was determined. Each replicate was weighed and calculations were made to convert the measurements to pounds per acre at 12% moisture.
3.3 Cultivar Studies, 1994

In 1994, three of the rice cultivars used in the 1993 studies, Lemont, Mars and Labelle, were cultivated using management practices similar to the previous year at the experimental station in Beaumont, Texas. The three cultivars were located within one field, 3.7 m x 56.3 m. The soil in this field, Bernard-Morey, was a fine montmorillonitic, thermic Vertic Ochraqualf. It was determined to contain sand, clay and silt in the ratio, 30%:27%:43%. Planting, flooding and draining dates occurred on April 5, May 17, and August 3, respectively.

The biomass experiments and data collection were designed and conducted by Yao Huang. Three biomass samples were collected weekly using the 0.2 x 0.2 m frames and procedure described in Section 2.4. For the scaling purposes, tillers of each variety were counted within both flux frames when biomass was collected. The biomass was sorted in aboveground live vegetative biomass, aboveground dead vegetative biomass and panicle biomass. Root biomass, including the weight of the crown, was determined for the cultivar, Lemont, only.

Methane emission measurements were again obtained by staff of the Texas A&M Agricultural Experimental Station at Beaumont, Texas, following the procedure described in Section 3.1. Two flux boxes were permenantly located within each of the three fields and were usually sampled twice weekly.
Grain yield was determined at harvest by the staff of the Texas A&M Agricultural Experimental Station. Grain was machine harvested. Yield was determined according to the procedure described in Section 3.2.
4. RESULTS

4.1 Plant Development

The data for developmental characteristics of the ten cultivars studied are shown in Table 4. All the varieties germinated and emerged by 10-12 days past planting or 29-31 days before flood. Mars was the only cultivar to emerge as early as 10 days past planting. Panicle differentiation among the cultivars spanned 16 days. Labelle, the fastest developing cultivar, reached PD at 61 days past planting, 20 days past flood, and Jasmine, the slowest developing cultivar, reached PD at 77 days past planting, or 36 days past flood. Heading occurred over a period of 18 days, 80-98 days past planting, or 39-57 days past flood. Again, Labelle and Jasmine were the fastest and slowest maturing varieties, respectively. Grain was harvested between 112 and 141 days past planting, 71 and 100 days past flood, with Labelle and Jasmine again determining the lower and upper boundaries of this period, respectively.

Plant development throughout the study was described using the 3 stabe model of plant development (Figure 1). The observed lengths of the three major developmental stages for the ten experimental cultivars were similar to the expected values. The greatest variance between cultivars was observed in the length of the vegetative stage. It lasted an average of 65.8 days with a standard
Table 4. Plant Development for Ten Cultivars.
Events are reported in days past planting (dpp). Phases are reported in days (d).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Emergence (dpp)</th>
<th>PD (dpp)</th>
<th>Heading (dpp)</th>
<th>Harvest (dpp)</th>
<th>Emergence to Heading (days)</th>
<th>Heading to Harvest (days)</th>
<th>Vegetative Phase (days)</th>
<th>Reproductive Phase (days)</th>
<th>Ripening Phase (days)</th>
<th>Total (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebonnet</td>
<td>12</td>
<td>70</td>
<td>85</td>
<td>121</td>
<td>74</td>
<td>36</td>
<td>65</td>
<td>17</td>
<td>30</td>
<td>112</td>
</tr>
<tr>
<td>Lemont</td>
<td>12</td>
<td>70</td>
<td>90</td>
<td>121</td>
<td>79</td>
<td>31</td>
<td>65</td>
<td>22</td>
<td>25</td>
<td>112</td>
</tr>
<tr>
<td>Dawn</td>
<td>12</td>
<td>73</td>
<td>92</td>
<td>128</td>
<td>81</td>
<td>36</td>
<td>68</td>
<td>21</td>
<td>23</td>
<td>112</td>
</tr>
<tr>
<td>Katy</td>
<td>12</td>
<td>71</td>
<td>90</td>
<td>119</td>
<td>79</td>
<td>29</td>
<td>66</td>
<td>21</td>
<td>25</td>
<td>112</td>
</tr>
<tr>
<td>Della</td>
<td>12</td>
<td>74</td>
<td>91</td>
<td>128</td>
<td>80</td>
<td>37</td>
<td>69</td>
<td>19</td>
<td>24</td>
<td>112</td>
</tr>
<tr>
<td>IR36</td>
<td>11</td>
<td>76</td>
<td>94</td>
<td>128</td>
<td>83</td>
<td>34</td>
<td>71</td>
<td>20</td>
<td>21</td>
<td>112</td>
</tr>
<tr>
<td>Mars</td>
<td>10</td>
<td>66</td>
<td>87</td>
<td>119</td>
<td>76</td>
<td>32</td>
<td>61</td>
<td>23</td>
<td>28</td>
<td>112</td>
</tr>
<tr>
<td>Brazos</td>
<td>12</td>
<td>70</td>
<td>84</td>
<td>119</td>
<td>73</td>
<td>35</td>
<td>65</td>
<td>16</td>
<td>31</td>
<td>112</td>
</tr>
<tr>
<td>Labelle</td>
<td>12</td>
<td>61</td>
<td>80</td>
<td>112</td>
<td>69</td>
<td>32</td>
<td>56</td>
<td>21</td>
<td>32</td>
<td>109</td>
</tr>
<tr>
<td>Jasmine</td>
<td>12</td>
<td>77</td>
<td>98</td>
<td>141</td>
<td>87</td>
<td>43</td>
<td>72</td>
<td>23</td>
<td>30</td>
<td>125</td>
</tr>
</tbody>
</table>
deviation of 4.49 days. The average length of the reproductive period among the cultivars was 20.3 days with a standard deviation of 2.24 days. This stage was the most consistent in length for the ten varieties studied. The ripening stage lasted an average of 26.9 days with a standard deviation of 3.59. The total length of development for all cultivars was 112 days, with the exceptions of Labelle, 109 days, and Jasmine, 125 days. The average length of development for the ten cultivars was 113 days with a standard deviation of 4.1.

4.2 Plant Height and Tiller Count

Plant height and tiller count data are shown for individual cultivars in Figures 6-15. The time scale for these measurements is given as Days Past Germination and also Days Past Flood. Flooding of the rice fields occurred approximately 38 days after the estimated germination time for the rice plants and about 30 days after their emergence (Stansel, 1975; personal communication, M. Jund). The developmental and agronomic events of panicle initiation, maximum tiller number, heading, field drain and harvest are also noted in these figures as they occurred over time for individual cultivars. Panicle initiation was estimated to occur 3 days prior to panicle differentiation (Stansel, 1975).

Eight of the ten cultivars exhibited tillering patterns similar to the model presented in Figure 1 (Yoshida, 1981). A peak in the numbers of tillers, followed by a decline and then leveling out, was
Figure 9. Stem Count and Plant Height for Katy
Figure 10: Stem Count and Plant Height for Delta
Figure 11. Stem Count and Plant Height for IR36
Figure 12. Stem Count and Plant Height for Mars
Figure 13. Stem Count and Plant Height for Brazos
Figure 14: Stem Count and Plant Height for Labelle
observed for all cultivars except Katy and Labelle. A peak in tiller number for Katy and Labelle may not have been observed due to the sampling schedule. The steep decline in the number of tillers observed for Lemont, Dawn, Della and Jasmine may have resulted from the use of two sampling methods (Section 2.4).

According to the model for rice plant growth, the consistent number of tillers reached at heading and maintained until maturity is equal to the number of panicles at maturity. This assumes that all tillers present at heading produce reproductive structures. The number of tillers producing panicles is affected by field management techniques, genetics and environmental conditions during the vegetative stage and, therefore, may vary from year to year (Stansel, 1975). When panicle number at 70 days past flood was compared to tiller number on this date, the average percentage of tillers bearing panicles was 71.1% (Figures 16a,b). The two cultivars with the lowest percentage of tillers with panicles were Brazos and Labelle, with 40% and 42%, respectively. Lebonnet had the highest percentage, 93%.

Compared to tiller number, the increase in plant height for the ten cultivars was less similar to the "characteristic" growth pattern. Della continued to increase in height after heading, contrary to this model. Plant height for all of the remaining cultivars may have continued to increase or may have remained constant after heading. These results are uncertain due to variation in the data. The data for
Figure 16a. Comparison of Post-Heading Tiller Number and Panicle Number

Figure 16b. Percentage of Tillers With Panicles
Jasmine are also somewhat inconclusive due to the extended maturation time of this cultivar.

All of the cultivars except Mars and Labelle can be classified as Type B rice plants (Figure 2). Type B rice plants are characterized by the coincidence of maximum tiller number and panicle initiation. Mars reached panicle initiation before maximum tiller number. Although the data for Labella were more variable, they suggest that Labelle behaved similarly. Consequently, both Mars and Labelle appeared to exhibit a shortened vegetative stage and were classified as Type A, or early-maturing, varieties. Heading may be staggered in this type of plant if late tillers produce panicles. None of the ten cultivars in this study was classified as a late-maturing variety, or Type C plant.

Data for post-heading plant height and tiller number, 63 days past flood, suggested similarities as well as differences between cultivars for these parameters (Figure 17a). The largest number of tillers, 613 tillers m⁻², was observed for IR36. This was a uniquely high value for number of tillers. The smallest number of tillers per square meter was recorded for Lebonnet at 321 tillers m⁻². The mean number of tillers for the ten cultivars was 415 tillers m⁻² with a standard deviation of 71.85. When IR36 was considered an outlier, the average tiller number for the remaining nine cultivars dropped to 393.15 tillers m⁻² with a standard deviation of 30.24.

As stated earlier, the data for plant height were variable and they suggest that Dawn, Della and Mars were the three tallest cultivars
with plant heights ranging from 125.6 cm to 127.9 cm (Figure 17b). Lemont, with a post-heading height of 95.9 cm, was the shortest cultivar. The plant height data for Lebonnet, Mars, and Labelle were the most variable of the ten cultivars.

4.3 Biomass Results

Aboveground live vegetative biomass (live stems and leaves), aboveground dead biomass and panicle biomass weight were measured eight times from flood to drain at approximately two week intervals. Belowground biomass (live and dead roots) and crown biomass were sampled with the aboveground plant biomass on five of the eight dates and at the same two week intervals. A summary of biomass data from 0-70 days past flood for samples which included aboveground and belowground biomass is given in Table A1. Data for biomass samples which measured aboveground biomass only are located in Table A2.

4.3.1 Seasonal Biomass Trends Within and Among Cultivars

Among the ten cultivars studied, the growth of aboveground live vegetative biomass and belowground biomass followed similar seasonal trends through heading (Figures 18, 19a). Both of these parameters increased steadily during this time. After the time by which most cultivars had headed, aboveground live vegetative
Figure 19a. Seasonal Root Biomass (0-10 cm)

Figure 19b. Seasonal Root Biomass (0-10 cm)
biomass remained at a constant value and root biomass increased sharply. This difference between aboveground live and belowground biomass trends may have resulted because aboveground live biomass included living tissue only and belowground biomass combined the masses of both living and dead roots.

The growth of aboveground live vegetative biomass for individual cultivars is shown in Figures 20a-29a. In general, aboveground live vegetative biomass increased rapidly during the first 40-50 days after flooding, leveled off between 50-63 days and then decreased during the final week of the season. Maximum aboveground live vegetative biomass ranged from 641.8 g m⁻² (Lebonnet) to 1284.9 g m⁻² (Jasmine). This value was attained near heading, approximately 40 to 50 days past flood, by most cultivars.

Differences in the developmental rates among the cultivars are apparent in the data. Lebonnet, which reached maximum aboveground live vegetative biomass by 30 days past flood, exhibited an unusually fast growth rate that was supported by data collected both 30 and 32 days past flood. All varieties except IR36 had reached their maximum value for this parameter by 63 days past flood. In Figures 20b-29b, graphs of smoothed data are presented in order to better estimate seasonal trends.

As shown in Figure 19, belowground biomass increased steadily during the season, slowly at first and then more rapidly near the end. Maximum root biomass was observed at 70 days past flood for most cultivars and ranged from 112.6 g m⁻² (Brazos) to 171.9 g
Figure 20a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Lebonnet

Figure 20b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Lebonnet (Smoothed Data)
Figure 21a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Lemont

Figure 21b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Lemont (Smoothed Data)
Figure 22a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Dawn

Figure 22b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Dawn (Smoothed Data)
Figure 23a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Katy

Figure 23b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Katy (Smoothed Data)
Figure 24a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Della

Figure 24b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Della (Smoothed Data)
Figure 25a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for IR36

Figure 25b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for IR36 (Smoothed Data)
Figure 26a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Mars

Figure 26b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Mars (Smoothed Data)
Figure 28a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Labelle

Figure 28b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Labelle (Smoothed Data)
Figure 29a. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Jasmine

Figure 29b. Aboveground Live Vegetative Biomass to 73 Days Past Flood for Jasmine (Smoothed Data)
m\(^{-2}\) (Jasmine). These measurements included both live and dead root material and, therefore, did not represent the same parameter as the aboveground analog. The data estimated accumulated root production over the season, but they did not indicate the amount of live, physiologically active tissue below ground or the level to which root senescence had progressed. Because of this, it was difficult to estimate when maximum root growth occurred, though it is predicted to occur with active tillering during the vegetative stage (Yoshida, 1981).

The distribution of root biomass by depth was measured for all cultivars. The change in procedures that was made at 63 days past flooding produced more accurate data and results using this method are shown in Figure 30. The percentage of root biomass, 0-10 cm, that was located in the first 5 cm of soil ranged from 56% (Lemont) to 86% (IR36) and had an average value of 67% for the ten cultivars.

Total live biomass data was determined by summing aboveground live, panicle, crown and belowground biomass, although the measurement for root biomass actually included a relatively small amount of dead root material. Figure 31 shows that total biomass trends, which were consistent among varieties, increased steadily during the growing season. The maximum total live biomass for cultivars, obtained for most varieties at 70 days past flood, ranged from 1158.6 g m\(^{-2}\), for IR36, to 1808.5 g m\(^{-2}\), for Dawn. Total live biomass included the weight of the panicle biomass and panicles filled at different rates for the ten cultivars. The variation in total live
Figure 30. Proportion of Total Root Biomass (0-5 Centimeters) at 63 Days Past Flood
Figure 31. Seasonal Total Live Biomass for Ten Cultivars

- Lebonnet
- Lemont
- Dawn
- Katy
- Della
- IR36
- Mars
- Brazos
- Labelle
- Jasmine

Biomass (g/m²)

Days Past Flood
biomass among cultivars was increased by differences in rates of grain filling.

4.3.2 Biomass Per Stem

In addition to determining biomass per square meter, aboveground live vegetative biomass and root biomass were also determined as weight per stem. The aboveground live vegetative biomass values ranged from 0.96 g stem\(^{-1}\) (IR36) to 3.01 g stem\(^{-1}\) (Jasmine) at 63 days past flood(Figure 32a). At the same time, belowground biomass ranged from a minimum of 0.15 g stem\(^{-1}\) (IR36) to a maximum of 0.39 g stem\(^{-1}\) (Jasmine). The total live vegetative biomass per stem (aboveground live vegetative biomass plus root biomass) averaged approximately 3.53 g stem\(^{-1}\). The average ratio between aboveground live vegetative biomass and root biomass, per stem, was 0.137.

Aboveground live vegetative biomass per stem was compared to aboveground live vegetative biomass per square meter. This resulted in a strong positive correlation (Figure 32b). The number of tillers per square meter varies little between nine of the cultivars (average=393.15, standard deviation=30.24, excluding IR36) and essentially functions as a constant when scaling biomass.
Figure 32a. Aboveground Live Vegetative Biomass and Root Biomass (0-10 cm) Per Tiller at 63 Days Past Flood

Figure 32b. Aboveground Live Vegetative Biomass per Tiller and Aboveground Live Vegetative Biomass per m² at 63 Days Past Flood

\[ y = 0.002x + 0.038 \quad r = 0.921 \]
4.3.3 Relationship Between Aboveground and Belowground Biomass

Aboveground live biomass was strongly and positively related to belowground biomass over the entire season. Figure 33a shows averaged, normalized aboveground live vegetative biomass versus belowground biomass data for all ten cultivars to 63 days past flood. The correlation coefficient between these averaged data was 0.973.

The root to shoot ratios for all ten cultivars are given in Figure 33b. These data also support the nature of the proportional growth which occurred between aboveground live vegetative biomass and belowground biomass for the cultivars. Root to shoot ratio trends were consistent for the ten cultivars during most of the flood period and did not show great variation between cultivars. The average root to shoot ratio, 30-63 days past flood, was 0.13 with a standard deviation of 0.014. The lowest ratio was associated with Mars, 0.11, and the highest occurred with IR36, 0.16. The ratios were considerably higher at the beginning and end of the season. The early values may have resulted from accelerated early root growth while the final root to shoot ratios were probably affected by a belowground measurement that included dead tissue and aboveground data that did not.
Figure 33a. Average Aboveground Live Vegetative Biomass and Root Biomass to 63 Days Past Flood (Normalized)

\[ y = 0.120x + 0.002 \quad r = 0.986 \]

Figure 33b. Seasonal Root to Shoot Ratio for Ten Cultivars
4.3.4 Biomass Partitioning Within and Among Cultivars

Figures 34-38 show the seasonal partitioning of the total biomass for individual cultivars. Aboveground live vegetative biomass increased at its most rapid rate during the first 50 days of flood. After this time, and for the remaining 43 days in the season, the panicles became the site of the most rapid growth, with a rate comparable to that of the early aboveground live vegetative biomass. At the end of the season, panicle weight was approximately equal to the weight of the aboveground live vegetative biomass. Root biomass and aboveground dead vegetative biomass gradually increased during the 73 day flood and both components showed little variation among cultivars.

While the remaining components of plant growth remained relatively constant, the panicle biomass was continuing to increase at the end of the season due to unfinished grain filling. It was also the plant component with the greatest variation was the mean panicle weight. The average weight for panicle biomass, among the ten cultivars at 70 days past flood, was 547.97 g m\(^{-2}\) with a standard deviation of 180.92 g m\(^{-2}\).

Figure 39a shows the averaged, normalized values for aboveground live, root, panicle and aboveground dead biomass with standard deviations at 63 days past flood. Biomass data for each cultivar were first normalized to the maximum aboveground live vegetative biomass recorded for that cultivar before averaging data.
Figure 34a. Seasonal Partitioning of Biomass for Lebonnet

Figure 34b. Seasonal Partitioning of Biomass for Lemont
Figure 35a. Seasonal Partitioning of Biomass for Dawn

Figure 35b. Seasonal Partitioning of Biomass for Katy
Figure 36a. Seasonal Partitioning of Biomass for Della

Figure 36b. Seasonal Partitioning of Biomass for IR36
Figure 37a. Seasonal Partitioning of Biomass for Mars

Figure 37b. Seasonal Partitioning of Biomass for Brazos
Figure 38a. Seasonal Partitioning of Biomass for Labelle

Figure 38b. Seasonal Partitioning of Biomass for Jasmine
Figure 39a. Average Seasonal Biomass Partitioning (Normalized)

Figure 39b. Average Biomass Partitioning (Normalized)
among the ten varieties. Figure 39b is an area graph of the same data from Figure 39a. In the area graph, each new biomass component added to the plot is summed with previous biomass constituents so that a net total is maintained. An estimate of the total accumulated biomass is shown in the profile formed by the uppermost curve and the partitioning of the total biomass during the season is presented. The growth of total biomass conforms very closely to that of a logistic function and produces a classically sigmoidal growth curve. The curve representing aboveground live vegetative biomass was affected by staggered heading dates for the cultivars and, therefore, maintains a maximum level for an artificially extended period of time.

4.3.5 Aboveground Dead Biomass Among Cultivars

The amount of dead material associated with the plant was determined for aboveground biomass only. Aboveground dead biomass was present as early as two weeks past flooding, and it increased steadily for most cultivars over the season. The proportion total biomass that was dead at the time of draining varied by a factor of about 2.5 between cultivars (Figure 40).

Only about 5% of the seasonal primary production of the cultivar, Labelle, was dead at drain compared to 13% of the production of Lemont and Katy. When panicle biomass weight is removed from the primary production total at drain, due to differences in grain filling rates among the cultivars, much more variation in
percentage dead biomass is apparent. The minimum and maximum percentages are still represented by Labelle and Lemont, respectively, but with panicle weight differences removed, the two cultivars vary by a factor of about 3.6.

4.3.6 Biomass Variation Among Cultivars

Aboveground live vegetative biomass and total aboveground biomass are shown for ten cultivars at 32, 51 and 63 days past flood in Table 5. These days coincide closely with the three developmentally significant periods of panicle differentiation, heading and active filling, respectively. Variation in aboveground live vegetative biomass among cultivars is comparable to variation in total aboveground biomass for all three stages.

The coefficients of variation in aboveground live vegetative biomass and total aboveground biomass ranged from 6.28 to 25.82. Biomass variability among rice cultivars increased during the season. For both categories of biomass, the coefficient of variation after 32 days past flood, approximately the vegetative growth phase, was 6.28. At the end of the season, however, variation in aboveground live vegetative biomass and total aboveground biomass increased to 25.82 and 20.77, respectively.
Table 5. 1993 Biomass Data for Ten Cultivars

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Aboveground Live Vegetative Biomass (g/m²)</th>
<th>Total Aboveground Biomass (g/m²)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32 Days Post Flood</td>
<td></td>
</tr>
<tr>
<td>Lebanon 1993</td>
<td>629.45</td>
<td>629.45</td>
</tr>
<tr>
<td>Lemont 1993</td>
<td>565.59</td>
<td>565.59</td>
</tr>
<tr>
<td>Dawn 1993</td>
<td>655.97</td>
<td>655.97</td>
</tr>
<tr>
<td>Kay 1993</td>
<td>570.34</td>
<td>570.34</td>
</tr>
<tr>
<td>Delta 1993</td>
<td>646.05</td>
<td>646.05</td>
</tr>
<tr>
<td>IR36 1993</td>
<td>598.42</td>
<td>598.42</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>624.14</td>
<td>624.14</td>
</tr>
<tr>
<td>Brazos 1993</td>
<td>604.27</td>
<td>604.27</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>630.99</td>
<td>630.99</td>
</tr>
<tr>
<td>Jasmine 1993</td>
<td>536.00</td>
<td>536.00</td>
</tr>
<tr>
<td>Average</td>
<td>606.72</td>
<td>606.72</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>38.11</td>
<td>38.11</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>6.28</td>
<td>6.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Aboveground Live Vegetative Biomass (g/m²)</th>
<th>Total Aboveground Biomass (g/m²)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>51 Days Post Flood</td>
<td></td>
</tr>
<tr>
<td>Lebanon 1993</td>
<td>762.94</td>
<td>989.69</td>
</tr>
<tr>
<td>Lemont 1993</td>
<td>737.15</td>
<td>963.07</td>
</tr>
<tr>
<td>Dawn 1993</td>
<td>989.25</td>
<td>1073.52</td>
</tr>
<tr>
<td>Kay 1993</td>
<td>854.63</td>
<td>1086.20</td>
</tr>
<tr>
<td>Delta 1993</td>
<td>942.02</td>
<td>1145.02</td>
</tr>
<tr>
<td>IR36 1993</td>
<td>991.76</td>
<td>1068.78</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>861.51</td>
<td>1168.03</td>
</tr>
<tr>
<td>Brazos 1993</td>
<td>721.48</td>
<td>837.03</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>694.30</td>
<td>1048.93</td>
</tr>
<tr>
<td>Jasmine 1993</td>
<td>833.71</td>
<td>871.13</td>
</tr>
<tr>
<td>Average</td>
<td>840.68</td>
<td>1023.46</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>108.30</td>
<td>109.58</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>12.88</td>
<td>10.69</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Aboveground Live Vegetative Biomass (g/m²)</th>
<th>Total Aboveground Biomass (g/m²)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>63 Days Post Flood</td>
<td></td>
</tr>
<tr>
<td>Lebanon 1993</td>
<td>634.05</td>
<td>1300.27</td>
</tr>
<tr>
<td>Lemont 1993</td>
<td>797.87</td>
<td>1144.66</td>
</tr>
<tr>
<td>Dawn 1993</td>
<td>1109.89</td>
<td>1593.67</td>
</tr>
<tr>
<td>Kay 1993</td>
<td>650.28</td>
<td>1251.57</td>
</tr>
<tr>
<td>Delta 1993</td>
<td>1029.12</td>
<td>1611.21</td>
</tr>
<tr>
<td>IR36 1993</td>
<td>586.34</td>
<td>838.37</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>916.84</td>
<td>1610.72</td>
</tr>
<tr>
<td>Brazos 1993</td>
<td>793.81</td>
<td>1119.46</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>963.47</td>
<td>1573.42</td>
</tr>
<tr>
<td>Jasmine 1993</td>
<td>1284.94</td>
<td>1742.98</td>
</tr>
<tr>
<td>Average</td>
<td>876.66</td>
<td>1380.64</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>226.31</td>
<td>286.69</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>25.82</td>
<td>20.77</td>
</tr>
</tbody>
</table>

*Aboveground and Vegetative Biomass data were not available
4.3.7 Biomass Differences Among Cultivars

Aboveground live vegetative biomass comparisons among mature cultivars were made using data collected between heading and 28 days past heading for each cultivar. These data were chosen because vegetative biomass was near maximum, relatively stable, and differences among the mature cultivars were most apparent. In order to increase sample number for each cultivar, the two replicates collected for each sample were considered separately, rather than averaged. Consequently, pseudoreplication was incorporated and may have increased the probability of significant differences.

A nonparametric test of medians was conducted to determine differences in aboveground live vegetative biomass among cultivars (Cochran, 1988). The median test is used to establish whether samples came from populations with the same medians (Cochran, 1988). The test assumes (1) samples are random, (2) samples are independent, (3) the scale of measurement is ordinal, interval or ratio, and (4) given equal population medians, populations have equal probability of an observation greater than the grand median. Unlike parametric analyses, samples are not assumed to fit a normal distribution (Heiman, 1992).

In Figure 41, a box and whisker technique is used to display the results of the median test. The median of each cultivar is represented by a white, horizontal bar. The 95% confidence interval for the estimated median is displayed as a light gray rectangle above and
below the median bar. The rectangular dark gray box, usually extending beyond the confidence interval, represents the interquartile range. The middle 50% of the biomass measurements, those in the second and third quartiles, occur in this region.

The "whiskers", or the dashed lines extending from the box and ending in a bar, are placed so that they encompass the biomass measurements within a distance of 1.5 times the interquartile range. Extreme biomass values outside whiskers are represented by open circles (Tukey, 1977). Finally, the dashed, horizontal line crossing all the boxes indicates the grand median, or the median of the combined biomass measurements of all the cultivars.

The results of the median test of aboveground live vegetative biomass showed significant differences between the cultivars. The cultivars were divided into two groups of high and low biomass which were significantly different from each other. The high biomass group contained the three cultivars, Dawn, Della and Jasmine. The low biomass group contained five cultivars, Lebonnet, Lemont, Katy, IR36 and Brazos. The remaining cultivars, Mars and Labelle, had intermediate medians with enough variability that they could not be distinguished from either the high or low biomass groups.

4.4 Root Porosity

The results of root porosity determinations for individual cultivars are shown in Figures 42-46. The seasonal trend for the
Figure 42a. Root Porosity During the Season for Lebonnet

Figure 42b. Root Porosity During the Season For Lemont
Figure 43a. Root Porosity During the Season For Dawn

Figure 43b. Root Porosity During the Season For Katy
Figure 44a. Root Porosity During the Season For Della

Figure 44b. Root Porosity During the Season For IR36
Figure 45a. Root Porosity During the Season For Mars

Figure 45b. Root Porosity During the Season For Brazos
Figure 46a. Root Porosity During the Season For Labelle

Figure 46b. Root Porosity During the Season For Jasmine
majority of cultivars was a steady increase in root porosity which reached maximum values during the reproductive or active filling stage and then declined near late filling. The cultivars which did not exhibit this trend were Katy, Brazos and Labelle, though due to the variation in the data of Katy and Labelle, the differences are less certain.

High variability was observed in some root porosity data. The most likely source of this was measurement error associated with very small, but critical differences in weight. Four samples were used per measurement, instead of the recommended ten, and this may have increased error (Jensen, 1969). Variation in the data may have been reduced by the determination and use of a constant density for root tissue among the cultivars using the second method, developed by Dr. Sass, beginning with the second root porosity determination.

Two determinations of root porosity were made for most cultivars prior to heading, at 30 and 43 days past flood, and the air space in roots appeared to increase during this time (Figure 47). The cultivars, Brazos and Labelle, headed by 43 days past flood and both cultivars showed a decrease in root porosity at that time. Of the remaining eight, pre-heading cultivars, only one, Katy, showed decreasing porosity.

The interpolated average root porosity of each cultivar at heading is given in Figure 48. Differences in root porosity are suggested although these were not tested due to limited samples. Lebonnet, Lemont, Della and Mars were estimated to have air space
Figure 48. Root Porosity at Heading for Ten Cultivars

- Jasmine
- Labellie
- Bressos
- Maris
- IR36
- Delta
- Key
- Dow
- Lamoni
- Loboosel

Porosity
at, or greater than, 34% of the total root volume at heading. In contrast, Brazos and Labelle had less than 20% root porosity at the same time.

4.5 Relative Chlorophyll

The seasonal trend in the relative amount of chlorophyll is shown in Figure 49a. In general, chlorophyll steadily declined during the season for all cultivars except Jasmine. The average chlorophyll among cultivars dropped from 40.58 spads (standard deviation = 4.03 spads) at 30 days past flood to 29.71 spads (standard deviation = 2.20 spads) at 70 days past flood.

The interpolated average relative chlorophyll at heading is shown for each cultivar in Figure 49b. A low of 28.44 spads was estimated for Jasmine compared to a high of 42.57 spads for Mars. The majority of cultivars were estimated at between 30 and 36 spads at heading. All relative chlorophyll measurements were subject to error due to the age, thickness and condition of the leaves sampled.

4.6 Qualitative Observations of Root and Aerenchyma Development

The development of roots was similar among cultivars. An early increase in root length was followed by the development of nodal, or adventitious roots, during the vegetative phase. Nodal roots for all cultivars appeared both light and dark colored and with varying
Figure 49a. Relative Chlorophyll During the Season

Figure 49b. Relative Chlorophyll at Heading
degrees of thickness at various times during the reproductive and ripening stages.

In general, the roots became somewhat browner or reddish-brown during the season, although high variability was observed within and among cultivars. A steady increase in root volume and roots per volume was observed for all cultivars. Dead roots were not readily distinguishable from live roots. Differences in root development among cultivars were not apparent.

An example of an aerenchyma tissue image prepared for qualitative observation is shown in Figure 50 using the cultivar, Della. Seasonal trends in aerenchyma development were not suggested by the observations. This may have resulted because (1) the observations were begun after the aerenchyma tissue was relatively developed and (2) the photograhic techniques used introduced effects such as shadows and tissue dessication which were not consistent within and among cultivars. The qualitative observations made of aerenchyma tissue in the stem before heading suggested no differences among cultivars. This occurred as a result of a high level of variability in cross-sectional area of aerenchyma within cultivars and error associated with photographic methods described above. In addition, unique red-brown circular areas, approximately 0.4 cm in diameter, were observed in some cross-sections at nodes of stems in the cultivar Dawn at 43 days past flood. This observation may have been related to the deposition of ferric iron within the aerenchyma due to the presence of oxygen.
Figure 50. Cross-Section of Stem Aerenchyma.
5. RESULTS OF RELATED RESEARCH

Research involving emission from irrigated rice fields, grain yield and rice plant biomass was conducted in 1993 and 1994 at the same time and location of this study. The emission and grain yield data were collected by staff of the Texas A&M Agricultural Experimental Station in Beaumont, Texas in both 1993 and 1994. Yao Huang, a graduate student at Rice University, collected plant biomass data in 1994. The data from their research that were related to this study's content are reported below and were used in its analysis.

5.1 Field Parameters

Mean daily air and soil temperatures and water levels were compiled by staff of the Texas A&M Agricultural Experimental Station while collecting emission data (Figure 51). Air temperature gradually and steadily increased from a low of 27.6°C at 16 days past flood to a high of 34.3°C near the end of the season. One isolated peak in air temperatures occurred on July 29 at 52 days past flood. Mean soil temperature remained relatively unchanged during the 74 day flooded period. The mean seasonal soil temperature for all ten fields was 25.2°C ± 0.6.

Although water management in all ten plots was consistent, the water levels in plots six through nine (IR36, Mars, Brazos and
Labelle) were about 30% lower than plots one through five and ten (Lebonnet, Lemont, Dawn, Katy, Della, Jasmine). The mean seasonal water depths for these two groups are shown in Figure 52. The water levels in most fields declined near the end of the season. During the last month of the study, the average depth was 11.25 cm in Group I, plots 1-5 and 10, and 4.08 cm in Group II, plots 6-9. The decrease in water levels was attributed to increased evaporation and changes in irrigation schedules.

The plots with IR36, Mars, Brazos and Labelle had significantly lower water levels than the fields to the east or west. This may have resulted from uneven leveling when the fields were prepared before planting (Fisher, personal communication). Although the water levels in these four fields were never recorded at less than 3.3 cm, exposed soil surfaces were reported by workers. At such extremely low water levels, the irregularities in the soil surface may have produced these random dry patches exposed to the atmosphere.

5.2 Methane Emission

Methane emission data were collected twice each week during the 74 day flood period for each cultivar by staff of the Texas A&M Agricultural Experimental Station. Although Jasmine was flooded for a total of 87 days, due to its extended vegetative stage, emission data were collected through 74 days only. Emission measurements were begun about two weeks after flooding, or 56 days past planting.
Emission data collected during the season for each cultivar are given in Table A3. Integrated total seasonal emission and average daily emission for the season are listed in Table 6.

Table 6. Total Seasonal Emission and Average Daily Emission for Ten Cultivars.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Total Seasonal Emission (g m⁻²)</th>
<th>Average Daily Emission (g m⁻² d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebonnet</td>
<td>24.34</td>
<td>333.45</td>
</tr>
<tr>
<td>Lemont</td>
<td>21.64</td>
<td>296.48</td>
</tr>
<tr>
<td>Dawn</td>
<td>22.40</td>
<td>306.87</td>
</tr>
<tr>
<td>Katy</td>
<td>19.97</td>
<td>273.51</td>
</tr>
<tr>
<td>Della</td>
<td>38.70</td>
<td>530.11</td>
</tr>
<tr>
<td>IR36</td>
<td>17.27</td>
<td>236.58</td>
</tr>
<tr>
<td>Mars</td>
<td>32.19</td>
<td>440.93</td>
</tr>
<tr>
<td>Brazos</td>
<td>18.68</td>
<td>255.83</td>
</tr>
<tr>
<td>Labelle</td>
<td>16.33</td>
<td>223.67</td>
</tr>
<tr>
<td>Jasmine</td>
<td>23.77</td>
<td>325.58</td>
</tr>
</tbody>
</table>

Seasonal emission data, from 16 days past flood to drain, are shown in Figure 53. In previous studies, a period of at least one week was required after flooding for the establishment of anaerobic conditions and the onset of significant methane emission in rice fields (Sass et al., 1990, 1991a). Methane emissions for all of the cultivars
were sampled on the same day, except Jasmine which was sampled on
the following day. Although Jasmine remained flooded for 87 days,
emission data collection ceased at 74 days of flood. Emissions for
Jasmine in 1993 were comparable to results reported for the same
cultivar in 1991 (Sass et al., 1991b).

5.3 Grain Yield

The grain yield of each cultivar, determined by staff of the
Texas A&M Agricultural Experimental Station, is shown in Tables 7
and A4.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Grain Yield (g m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebonnet</td>
<td>604.55</td>
</tr>
<tr>
<td>Lemont</td>
<td>731.48</td>
</tr>
<tr>
<td>Dawn</td>
<td>707.93</td>
</tr>
<tr>
<td>Katy</td>
<td>685.45</td>
</tr>
<tr>
<td>Della</td>
<td>624.86</td>
</tr>
<tr>
<td>IR36</td>
<td>808.05</td>
</tr>
<tr>
<td>Mars</td>
<td>730.57</td>
</tr>
<tr>
<td>Brazos</td>
<td>597.14</td>
</tr>
<tr>
<td>Labelle</td>
<td>466.66</td>
</tr>
<tr>
<td>Jasmine</td>
<td>550.84</td>
</tr>
</tbody>
</table>
Cultivar yields varied by a factor of 1.7 and ranged from 466.66 g m\(^{-2}\) for Labelle to 808.05 g m\(^{-2}\) for IR36 (Figure 54). The 1993 grain yield of Jasmine was comparable to results reported in 1990 (Sass et al., 1990).

5.4 Biomass and Emission Results for 1994 Cultivar Studies

The cultivars, Lemont, Mars and Labelle were used in 1994 field studies at the Texas A&M Agricultural Experimental Station in Beaumont, Texas. Plant biomass data and emission data were collected by Yao Huang and staff of the Texas A&M Agricultural Experimental Station, respectively. The fields were planted on April 5, 1994 by staff at the station.

Important developmental events for the cultivars grown in 1994 are given in days past planting in Table 8. The three varieties emerged 13 days after planting. Lemont and Mars developed at

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Emergence</th>
<th>PD*</th>
<th>Heading</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemont</td>
<td>13</td>
<td>76</td>
<td>98</td>
<td>128</td>
</tr>
<tr>
<td>Mars</td>
<td>13</td>
<td>72</td>
<td>94</td>
<td>128</td>
</tr>
<tr>
<td>Labelle</td>
<td>13</td>
<td>65</td>
<td>86</td>
<td>111</td>
</tr>
</tbody>
</table>

*Panicle Differentiation. All data reported in days past planting.
similar rates, with heading occurring at 98 and 94 days past planting, respectively, and harvest at 128 days past planting. Although Labelle emerged at the same time as Lemont and Mars, Labelle developed faster and was harvested more than two weeks earlier than the other two cultivars, at 111 days past planting.

Biomass data for the 1994 cultivars, collected by Yao Huang, are given in Table A5. Seasonal trends for aboveground live vegetative biomass, which peaked near heading and then declined, were similar among cultivars. Maximum aboveground live biomass ranged from Labelle, 633.5 g m\(^{-2}\) at 34 days past flood, to Lemont, 784.6 g m\(^{-2}\) at 57 days past flood (Figure 55a). The total aboveground biomass occurred among cultivars in the same relative order as aboveground live vegetative biomass.

Methane emission data for 1994, collected by staff at the Texas A&M Agricultural Experimental Station, are also given in Table A5. Emissions for Lemont, Mars and Labelle rose steadily and then peaked sometime during the reproductive stage of each cultivar. Maximum daily emission ranged from Labelle, 439 g m\(^{-2}\) d\(^{-1}\), to Mars, 929.9 g m\(^{-2}\) d\(^{-1}\) (Figure 55b). The total accumulated seasonal emissions for Lemont, Mars and Labelle were 17.95 g m\(^{-2}\), 34.26 g m\(^{-2}\) and 15.95 g m\(^{-2}\), respectively.
Figure 55a. 1994 Aboveground Live Vegetative Biomass for Lemont, Mars and Labelle (Data: Huang, 1994)

Figure 55b. 1994 Average Daily Emission for Lemont, Mars and Labelle
6. DISCUSSION

6.1 Biomass Partitioning Trends Among Cultivars

Figure 56a gives seasonal biomass trends for the ten cultivars using normalized and averaged data. Each biomass component of an individual cultivar was normalized to the maximum aboveground live vegetative biomass sample observed for that cultivar. The data for all cultivars on each sampling date were then averaged. Mean total biomass and its two principal constituents, aboveground live vegetative biomass and panicle biomass, are shown. Panicle biomass includes the weight of the grain plus the structural tissue supporting it.

It is apparent that the rate of aboveground live vegetative biomass increase occurring early in the season is essentially maintained as panicle biomass increases later in the season. In Figure 56b, aboveground live biomass, between 16-32 days past flood, is plotted next to panicle biomass, between 51-70 days past flood. The slopes of the aboveground live biomass and panicle biomass curves, representing the rate of biomass increase, are 0.32 g m\(^{-2}\) and 0.29 g m\(^{-2}\), respectively. In addition, it appears from the results of this study that the carbohydrates stored in the early season are not sufficient to account for the entire increase in the panicle biomass. This is consistent with previous reports that carbohydrates
Figure 56a. Comparison of Average Aboveground Live Vegetative, Panicle and Total Biomass Growth

Figure 56b. Comparison of Growth of Aboveground Vegetative Live Biomass (16-32 Days) and Panicle Biomass (51-70 Days)
accumulated in the leaves and sheathes before filling account for 0-40% of grain carbohydrate (Yoshida, 1981).

The increase in grain weight which occurs during panicle maturation depends more on upper leaves while the lower leaves support the roots (Yoshida, 1981). Though sink proximity usually determines the movement of photosynthates from sources, it has been reported that rice plants are able to make changes in how photosynthates are partitioned in response to stress (King, et al., 1967). The results shown in Figure 56a suggest that the varieties in this study manufacture sugar at a uniform rate during the season and shift the allocation of products at the end of their reproductive stage.

6.2 Methane Emission Trends Among Cultivars

Methane emission trends were most consistent among cultivars until heading or one week after heading. In general, the methane emission of individual cultivars continuously increased during its vegetative stage and peaked sometime during its reproductive period, between panicle differentiation and heading (Figures 57-61). All cultivars headed, and their associated methane emissions had peaked, by 57 days past flooding.

After heading, methane emissions were much less consistent among cultivars. Emissions for six of the ten cultivars (Katy, IR36, Mars, Brazos, Labelle, and Jasmine) declined slightly after heading and then increased near the end of the season. Three of the four
Figure 57a. Average Daily Emission for Lebonnet to 73 Days Past Flood

Figure 57b. Average Daily Emission for Lemont to 73 Days Past Flood
Figure 58a. Average Daily Emission for Dawn to 73 Days Past Flood

Figure 58b. Average Daily Emission for Katy to 73 Days Past Flood
Figure 59a. Average Daily Emission for Della to 73 Days Past Flood

Figure 59b. Average Daily Emission for IR36 to 73 Days Past Flood
Figure 60a. Average Daily Emission for Mars to 73 Days Past Flood

Figure 60b. Average Daily Emission for Brazos to 73 Days Past Flood
Figure 61a. Average Daily Emission for Labelle to 73 Days Past Flood

Figure 61b. Average Daily Emission for Jasmine to 73 Days Past Flood
remaining varieties (Lebonnet, Dawn and Della) exhibited sharp increases after heading and then declined. The emissions of the remaining cultivar, Lemont, declined steadily, with no increases, until the fields were drained. Three cultivars (Lebonnet, Lemont and Della) had unexplained, elevated spikes in emission measurements recorded at one of the two flux chambers in their respective fields at or shortly after draining. Peaks which occurred after drain may have involved post-season degassing of the soil.

Early flux data were highly predictive of total seasonal flux (Huang, personal communication). From the data shown in Table 6, a highly significant autocorrelation resulted among cultivars using the cumulative seasonal emission to 51 days past flood and to 30 days past flood. The correlation coefficient for the relationship was $r=0.927^{**}$. Cumulative seasonal emissions to 30 days past flood autocorrelated with cumulative seasonal emissions to 63 days past flood with a correlation coefficient of $0.894^{**}$. Finally, a correlation coefficient of $r=0.990^{**}$ was produced by the autocorrelation between cumulative seasonal emission to 64 days past flood and the cumulative seasonal emission to 51 days past flood.

6.3 Variation in Emission Among Cultivars

Average daily emission and cumulative emission are shown for ten cultivars at 32, 51 and 63 days past flood in Table 9. These days coincide closely with the three developmentally significant periods of
Table 9. 1993 Emission Data for Ten Cultivars

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>32 Days Past Flood</th>
<th>51 Days Past Flood</th>
<th>63 Days Past Flood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily Emission (mg/m²/d)</td>
<td>Cumulative Emission (g/m²)</td>
<td>Daily Emission (mg/m²/d)</td>
</tr>
<tr>
<td>Lbbonnet 1993</td>
<td>315.39</td>
<td>3.07</td>
<td>474.18</td>
</tr>
<tr>
<td>Lemon 1993</td>
<td>300.87</td>
<td>2.58</td>
<td>528.97</td>
</tr>
<tr>
<td>Dawn 1993</td>
<td>300.30</td>
<td>3.07</td>
<td>455.32</td>
</tr>
<tr>
<td>Katy 1993</td>
<td>279.76</td>
<td>3.38</td>
<td>406.40</td>
</tr>
<tr>
<td>Delta 1993</td>
<td>556.85</td>
<td>5.68</td>
<td>1151.04</td>
</tr>
<tr>
<td>IR36 1993</td>
<td>185.55</td>
<td>2.75</td>
<td>564.54</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>711.65</td>
<td>6.89</td>
<td>626.54</td>
</tr>
<tr>
<td>Brazos 1993</td>
<td>288.52</td>
<td>2.91</td>
<td>-443.33</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>334.55</td>
<td>3.22</td>
<td>272.05</td>
</tr>
<tr>
<td>Jasmine 1993</td>
<td>472.98</td>
<td>3.85</td>
<td>854.47</td>
</tr>
<tr>
<td>Average</td>
<td>374.64</td>
<td>3.74</td>
<td>549.88</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.58.01</td>
<td>1.41</td>
<td>230.45</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>42.18</td>
<td>37.82</td>
<td>41.91</td>
</tr>
</tbody>
</table>
panicle differentiation, heading and active filling, respectively. Variation in daily emission data is comparable to variation in cumulative emission data for all three stages. The coefficients of variation in emissions for both daily and cumulative emission decrease during the season from 42.18 and 37.82 to 22.38 and 30.92, respectively.

When variation in the emission data is compared to variation in the biomass data, two important relationships are evident (Tables 5 and 6). First, overall variation in daily emission among cultivars is greater than for the overall variation in aboveground live vegetative biomass. For example, the largest coefficient of variation shown for daily emission is 42.18, whereas the coefficient of variation for aboveground live vegetative biomass never exceeded 25.82. Second, the trends of variation in emission are inverse of the trends of variation in biomass. Variation in daily emission decreases during the season from 45.18, during the vegetative stage, to 22.38, during filling. At the same time variation in emission is decreasing, variation among cultivars in aboveground live vegetative biomass is increasing from 6.28 to 25.82. In other words, methane emission is most varied among cultivars at the time aboveground live vegetative biomass is most similar. Conversely, when variation in emission is at its lowest among cultivars, biomass is most varied.
6.4 Emission Differences Among Cultivars

Although the seasonal trends for methane emissions were comparable through heading among cultivars, the magnitude of average daily emissions of the individual cultivars varied greatly. On one date during this period, methane from the highest emitting variety, Della, was 4.8 times greater than that of the lowest emitting variety, Labelle. Over the entire season, the emissions of these two varieties differed by a factor of 2.4.

Total seasonal emissions of the ten cultivars were compared using a nonparametric test of medians and average daily emission data for the total season (Cochran, 1988). In addition, methane emissions of developmentally equivalent plants were compared using the same test of medians and emission data collected during the reproductive phase of the individual cultivars. The results of the median test are shown in Figures 62 and 63.

When emission data from the total season were used in the analysis, the cultivars sorted into three groups, with the high and low groups being different from each other but not from the middle group. The high group contained two cultivars, Della and Mars. The low group also contained two cultivars, IR36 and Labelle. The remaining cultivars, Lebonnet, Lemont, Dawn, Katy, Brazos and Jasmine, constituted the intermediate emission group that was not significantly different from the high and low groups.
Figure 62. Comparison of Seasonal Methane Emissions for Ten Cultivars
Figure 63. Comparison of Emissions From PD to Heading for Ten Cultivars
With data limited to the daily emission during reproductive stage of the rice, panicle differentiation to heading, two emission groups resulted. Mars and Della remained in the high emission group. The other eight cultivars, previously divided into two groups using seasonal emissions, formed a group with significantly lower emissions. Within the low emission group, the emissions of Jasmine were significantly higher than Dawn, Katy and Labelle, but were indistinguishable from the other cultivars in the group. Dawn, Katy and Labelle were not significantly different from any of the remaining five cultivars. The increase in size of the 95% confidence intervals was related to the limited data available from the reproductive phase of each cultivar.

The average daily emission during the season for the two emission groups resulting from the reproductive median test (Figure 63) are plotted in Figure 64. The two emission groups showed similar seasonal trends. Emissions for both increased until near heading, at which time the higher emission group decreased and the lower group remained fairly constant. At 71 days past flood, emissions of both groups increased and then declined steadily to the end of the season. The second seasonal maxima of the high emission group was much greater than that of the low group.

Prior to the average heading date for each group, the standard deviations of the groups coincided only twice. On these two days, the variation for emissions in the high group was large and perhaps due to the difference between the developmental rates of Della and
Figure 64. Average Daily Emission for Two Groups Determined Through Reproductive Stage Emission Differences

- Group I: Lebonnet, Lemont, Dawn, Katy, IR36, Brazos, Labelle, Jasmine
- Group II: Della, Mars
Mars as well as the limited number of data (Tables 4 and A3). After the groups' average heading dates, and especially after 59 days past flood, the differences in emission trends of the groups are less distinct. This may be related to the late-season variability in emissions observed among individual cultivars, or due to the presence of other carbon sources in the system.

An alternative display of the emission data for the ten cultivars, developed by Dr. Ronald L. Sass, presents the data expressed as accumulated seasonal emission in Figure 65. The accumulated emission curves were produced by summing the integrated values for emission during the season. With the absence of sub-seasonal fluctuations, the differences among cultivars in the total methane emission accumulated during the season were more apparent.

The two groups of cultivars, resulting from median tests of reproductive stage emission, are evident in the plot of accumulated seasonal emission (Figure 65). The higher emission group consisted of the two cultivars, Della and Mars, while the lower group contained the remaining eight cultivars. Although Jasmine exhibited elevated emissions between 43 and 58 days past flooding, it began and ended the season closely associated with the low emission group and its total accumulated methane is within the range for that group. These results may have been affected by root and aboveground biomass from the previous season that was incorporated into this plot only.
The cultivars began to sort into two groups at 25 to 30 days past flood, a time when most cultivars were entering their reproductive period. The groups were more clearly established by 50 days past flood, near heading for most varieties, and maintained their relative differences until the end of the season. The average slope, or the average daily increment, plotted for the group containing Mars and Della from 24 to 73 is 0.7103 g CH4 d\(^{-1}\). The average slope for the remaining eight cultivars is 0.416 g CH4 d\(^{-1}\).

The total accumulated seasonal emissions for all cultivars, with 95% error bars determined using error accumulated during the season, are shown in Figure 66. Like the results of the median test of reproductive stage emissions, the emissions of Della and Mars were significantly different from the other varieties and indistinguishable from each other. Within the lower emission group, however, increased differences among cultivars resulted using accumulated seasonal emission data than individual reproductive stage emission data.

Although the large amount of data available for accumulated seasonal emission comparisons contributed to increased resolution within the low emission group, this level of discrimination may not be important for interpreting varietal emission differences. While the test of reproductive stage medians indicated differences only between Jasmine and a group containing Dawn, Katy, and Labelle, the comparison of accumulated seasonal emissions among low-emitting cultivars showed numerous differences within the group.
Emission data collected during the vegetative and the ripening stages indicates that the relative emissions of cultivars in the low-emission group varied between the two periods. This suggests that the range of emissions within the group is large and variability is present with little effect.

6.5 Comparison of 1993 and 1994 Biomass and Emission Results

Although the 1994 fields were planted 22 days earlier than fields in 1993, the development of Lemont, Mars and Labelle was similar in both years (Table 10). The length of time from planting to heading in 1994 was within 6 to 8 days of the same period in 1993 for all three cultivars. The difference in total maturation

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>PD*</th>
<th>Heading</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemont 1993</td>
<td>70</td>
<td>90</td>
<td>121</td>
</tr>
<tr>
<td>Lemont 1994</td>
<td>76</td>
<td>98</td>
<td>128</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>66</td>
<td>87</td>
<td>119</td>
</tr>
<tr>
<td>Mars 1994</td>
<td>72</td>
<td>94</td>
<td>128</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>62</td>
<td>80</td>
<td>112</td>
</tr>
<tr>
<td>Labelle 1994</td>
<td>65</td>
<td>86</td>
<td>111</td>
</tr>
</tbody>
</table>

*Panicle Differentiation; All data are reported as days past planting.
length between 1993 and 1994 varied from one day, for Labelle, to a week, for Mars.

Biomass data collected over two years for the cultivars, Lemont, Mars and Labelle, at three developmentally significant periods are shown in Table 11. Data for all ten of the experimental cultivars studied during this time are included. The data reported for 1994 were collected by Yao Huang. The time for which data are reported, 30, 51 and 64 days past flood, represent the approximate periods of panicle differentiation, heading and active filling, respectively, for the majority of the cultivars listed. The biomass is given in the catagories of aboveground live vegetative biomass and total aboveground biomass.

Differences in total aboveground vegetative biomass among mature varieties are shown for both years in Figure 67. Biomass for Lemont and Mars varied significantly and inversely between 1993 and 1994, with Lemont increasing and Mars decreasing in the second year. Although the 95% confidence intervals for Labelle in 1993 slightly coincide with those for Labelle in 1994, the biomass for this cultivar may also, in fact, be different between the two years for this cultivar. Total aboveground vegetative biomass measurements for Labelle and Mars, in 1994, are significantly lower than most cultivars in both years.

Methane emission data for ten cultivars collected by staff of the Texas A&M Agricultural Experimental Research Station over two years, at 30, 51 and 64 days past flood, are given in Table 12.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>29/30 Days Post Flood</th>
<th>50/51 Days Post Flood</th>
<th>63/64 Days Post Flood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aboveground Live Vegetative Biomass (g/m²)</td>
<td>Total Aboveground Biomass (g/m²)</td>
<td>Aboveground Live Vegetative Biomass (g/m²)</td>
</tr>
<tr>
<td>Lebanon1993</td>
<td>620.48</td>
<td>640.09</td>
<td>634.05</td>
</tr>
<tr>
<td>Lemont1993</td>
<td>355.10</td>
<td>363.20</td>
<td>793.87</td>
</tr>
<tr>
<td>Dawn1993</td>
<td>257.25</td>
<td>266.44</td>
<td>1109.89</td>
</tr>
<tr>
<td>Katy1993</td>
<td>383.92</td>
<td>393.70</td>
<td>1265.12</td>
</tr>
<tr>
<td>Della1993</td>
<td>411.75</td>
<td>418.79</td>
<td>806.74</td>
</tr>
<tr>
<td>IR361993</td>
<td>507.54</td>
<td>517.42</td>
<td>1096.78</td>
</tr>
<tr>
<td>Mars1993</td>
<td>417.81</td>
<td>434.19</td>
<td>1168.63</td>
</tr>
<tr>
<td>Honest1993</td>
<td>360.81</td>
<td>369.04</td>
<td>1068.78</td>
</tr>
<tr>
<td>Labelle1993</td>
<td>371.09</td>
<td>378.61</td>
<td>1096.78</td>
</tr>
<tr>
<td>Jasmine1993</td>
<td>277.35</td>
<td>311.09</td>
<td>1168.63</td>
</tr>
<tr>
<td>Lemont1994</td>
<td>427.20</td>
<td>436.80</td>
<td>1068.78</td>
</tr>
<tr>
<td>Mars1994</td>
<td>379.00</td>
<td>399.90</td>
<td>1168.63</td>
</tr>
<tr>
<td>Labelle1994</td>
<td>447.20</td>
<td>458.30</td>
<td>1068.78</td>
</tr>
<tr>
<td>Average</td>
<td>498.96</td>
<td>421.44</td>
<td>1168.63</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>83.92</td>
<td>83.46</td>
<td>13.17</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>19.98</td>
<td>19.38</td>
<td>1.44</td>
</tr>
</tbody>
</table>
### Table 12. 1993 and 1994 Emission Data for Ten Cultivars

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>29/30 Days Past Flood</th>
<th>51 Days Past Flood</th>
<th>64 Days Past Flood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily Emission (mg/m²/d)</td>
<td>Cumulative Emission (g/m²)</td>
<td>Daily Emission (mg/m²/d)</td>
</tr>
<tr>
<td>Lebonnet 1993</td>
<td>286.80</td>
<td>2.43</td>
<td>426.91</td>
</tr>
<tr>
<td>Lemont 1993</td>
<td>204.90</td>
<td>1.93</td>
<td>486.25</td>
</tr>
<tr>
<td>Dawn 1993</td>
<td>268.59</td>
<td>2.45</td>
<td>479.89</td>
</tr>
<tr>
<td>Katy 1993</td>
<td>252.13</td>
<td>2.81</td>
<td>456.71</td>
</tr>
<tr>
<td>Della 1993</td>
<td>451.60</td>
<td>4.52</td>
<td>416.96</td>
</tr>
<tr>
<td>IR36 1993</td>
<td>136.80</td>
<td>2.35</td>
<td>337.64</td>
</tr>
<tr>
<td>Mars 1993</td>
<td>570.31</td>
<td>5.39</td>
<td>348.35</td>
</tr>
<tr>
<td>Baron 1993</td>
<td>141.07</td>
<td>2.26</td>
<td>348.35</td>
</tr>
<tr>
<td>Labelle 1993</td>
<td>319.32</td>
<td>2.54</td>
<td>348.35</td>
</tr>
<tr>
<td>Jasmine 1993</td>
<td>319.78</td>
<td>2.56</td>
<td>348.35</td>
</tr>
<tr>
<td>Lemont 1994</td>
<td>230.70</td>
<td>1.24</td>
<td>265.60</td>
</tr>
<tr>
<td>Mars 1994</td>
<td>542.40</td>
<td>4.52</td>
<td>384.40</td>
</tr>
<tr>
<td>Labelle 1994</td>
<td>204.80</td>
<td>2.26</td>
<td>Average</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>137.31</td>
<td>1.19</td>
<td>223.79</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>45.06</td>
<td>41.05</td>
<td>40.92</td>
</tr>
</tbody>
</table>
The data are given as emission observed at the time of collection (mg m\(^{-2}\) d\(^{-1}\)) and as the cumulative methane emission to the time of collection (g m\(^{-2}\)).

Emission differences among the ten experimental cultivars used in 1993 and 1994 are shown in Figure 68 and the emission differences among varieties were consistent between the two years. The results from 1994 support the results of the 1993 analysis in which the ten cultivars were divided into two emission groups. Although the median reproductive emission for Mars in 1994 was very comparable to the 1993 median, emission in 1994 was highly variable and the confidence intervals are much larger. Consequently, Mars cannot be differentiated from cultivars in the low emission group. The cultivars, Lemont and Labelle remained in the low emission group although they reversed their relative order between 1993 and 1994.

Three important results for 1993 are supported by the 1994 data. First, there was much more consistency and similarity among cultivars for aboveground live vegetative biomass and emission trends through heading, or shortly afterwards, than during ripening. Both aboveground live vegetative biomass and average daily emission steadily increased until near heading for most cultivars. After heading, biomass either continued to increase or plateaued while emission usually declined. This coincided with the physiological process of grain filling by rice plants during the ripening stage.
Second, data for aboveground live vegetative biomass data was less variable than data for daily methane emission. This was true for all developmental stages during the season. In addition, variability in biomass and emission data was inversely related. Emission data showed more variation during the vegetative stage when biomass data were most similar among cultivars. During the ripening stage, this relationship was reversed.

Third, differences in seasonal aboveground live vegetative biomass and methane emission among cultivars did not coincide. The cultivars with the lowest and highest methane emissions in 1993, Labelle and Della, were both among the cultivars with the greatest biomass during that season. Also, though the emissions of Mars were consistently among the highest in both years, its mature aboveground live vegetative biomass varied from average, in 1993, to one of the lowest, in 1994.

6.6 Biomass and Methane Emission Within Cultivars

Aboveground live vegetative biomass, aboveground dead vegetative biomass, total aboveground vegetative biomass and total aboveground biomass were each plotted against average daily emission, by cultivar, for 0-50, 0-63 and 0-73 days past flood. The Pearson correlation coefficients for these results are shown in Table 13. The significance of the results is indicated at the 5% (*) and 1% (**) levels.
Table 13. Pearson Correlation Coefficient for Methane Emission With Four Biomass Categories During Three Time Periods

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Live Aboveground</th>
<th>Dead Aboveground</th>
<th>Total Aboveground</th>
<th>Total Vegetative</th>
<th>Total Aboveground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lébonnet</td>
<td>0.924*</td>
<td>0.750</td>
<td>0.928*</td>
<td>0.917*</td>
<td></td>
</tr>
<tr>
<td>Lemont</td>
<td>0.968**</td>
<td>0.899*</td>
<td>0.971**</td>
<td>0.959*</td>
<td></td>
</tr>
<tr>
<td>Dawn</td>
<td>0.804</td>
<td>0.692</td>
<td>0.804</td>
<td>0.799</td>
<td></td>
</tr>
<tr>
<td>Katy</td>
<td>0.986**</td>
<td>0.916*</td>
<td>0.987**</td>
<td>0.982**</td>
<td></td>
</tr>
<tr>
<td>Della</td>
<td>0.874</td>
<td>0.831</td>
<td>0.891*</td>
<td>0.887*</td>
<td></td>
</tr>
<tr>
<td>1R36</td>
<td>0.873</td>
<td>0.936*</td>
<td>0.885*</td>
<td>0.887*</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>0.858</td>
<td>0.593</td>
<td>0.845</td>
<td>0.758</td>
<td></td>
</tr>
<tr>
<td>Brazos</td>
<td>0.941*</td>
<td>0.957*</td>
<td>0.948*</td>
<td>0.943*</td>
<td></td>
</tr>
<tr>
<td>Labelle</td>
<td>0.845</td>
<td>0.270</td>
<td>0.826</td>
<td>0.693</td>
<td></td>
</tr>
<tr>
<td>Jasmine</td>
<td>0.816</td>
<td>0.793</td>
<td>0.819</td>
<td>0.819</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Live Aboveground</th>
<th>Dead Aboveground</th>
<th>Total Aboveground</th>
<th>Total Vegetative</th>
<th>Total Aboveground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lébonnet</td>
<td>0.92**</td>
<td>0.584</td>
<td>0.934**</td>
<td>0.829*</td>
<td></td>
</tr>
<tr>
<td>Lemont</td>
<td>0.964**</td>
<td>0.782</td>
<td>0.963**</td>
<td>0.919*</td>
<td></td>
</tr>
<tr>
<td>Dawn</td>
<td>0.877*</td>
<td>0.759</td>
<td>0.879*</td>
<td>0.864*</td>
<td></td>
</tr>
<tr>
<td>Katy</td>
<td>0.954**</td>
<td>0.810</td>
<td>0.975**</td>
<td>0.964**</td>
<td></td>
</tr>
<tr>
<td>Della</td>
<td>0.585</td>
<td>0.385</td>
<td>0.560</td>
<td>0.417</td>
<td></td>
</tr>
<tr>
<td>1R36</td>
<td>0.867*</td>
<td>0.887*</td>
<td>0.883*</td>
<td>0.886*</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>0.676</td>
<td>0.206</td>
<td>0.638</td>
<td>0.385</td>
<td></td>
</tr>
<tr>
<td>Brazos</td>
<td>0.891*</td>
<td>0.666</td>
<td>0.887</td>
<td>0.790</td>
<td></td>
</tr>
<tr>
<td>Labelle</td>
<td>0.671</td>
<td>0.110</td>
<td>0.623</td>
<td>0.456</td>
<td></td>
</tr>
<tr>
<td>Jasmine</td>
<td>0.422</td>
<td>0.179</td>
<td>0.404</td>
<td>0.317</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Live Aboveground</th>
<th>Dead Aboveground</th>
<th>Total Aboveground</th>
<th>Total Vegetative</th>
<th>Total Aboveground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lébonnet</td>
<td>0.549</td>
<td>0.695</td>
<td>0.663</td>
<td>0.699</td>
<td></td>
</tr>
<tr>
<td>Lemont</td>
<td>0.932**</td>
<td>0.214</td>
<td>0.869**</td>
<td>0.559</td>
<td></td>
</tr>
<tr>
<td>Dawn</td>
<td>0.857**</td>
<td>0.678</td>
<td>0.86**</td>
<td>0.785*</td>
<td></td>
</tr>
<tr>
<td>Katy</td>
<td>0.833*</td>
<td>0.584</td>
<td>0.866**</td>
<td>0.848**</td>
<td></td>
</tr>
<tr>
<td>Della</td>
<td>0.653</td>
<td>0.468</td>
<td>0.641</td>
<td>0.537</td>
<td></td>
</tr>
<tr>
<td>1R36</td>
<td>0.861**</td>
<td>0.452</td>
<td>0.857**</td>
<td>0.747*</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>0.633</td>
<td>0.304</td>
<td>0.611</td>
<td>0.430</td>
<td></td>
</tr>
<tr>
<td>Brazos</td>
<td>0.855**</td>
<td>0.424</td>
<td>0.866**</td>
<td>0.701</td>
<td></td>
</tr>
<tr>
<td>Labelle</td>
<td>0.649</td>
<td>0.622</td>
<td>0.674</td>
<td>0.681</td>
<td></td>
</tr>
<tr>
<td>Jasmine</td>
<td>0.324</td>
<td>0.023</td>
<td>0.294</td>
<td>0.152</td>
<td></td>
</tr>
</tbody>
</table>

*,** significance at the 5% and 1% level, respectively
Within cultivars, the strongest biomass-emission relationship occurred with total aboveground vegetative biomass (live plus dead vegetative tissue). Two cultivars, Lemont and Katy, had correlation coefficients between total aboveground vegetative biomass and average daily emissions that were significant at the 1% level during all three time periods observed. For the 50 and 73 day periods, this biomass category contained the greatest number of cultivars with significant results as well as the highest average level of significance.

Aboveground live vegetative biomass was only slightly less effective than total aboveground vegetative biomass for predicting methane emissions within cultivars. The weight of the developing panicles, which was included in the total aboveground biomass, appeared to reduce the level of correlation between biomass and emission.

The results from this study involving seasonal trends in biomass and methane emission suggest that the relationship between biomass and methane is coupled to the development of rice plant biomass. The findings are consistent with results reported in a number of other studies (Gross et al., 1993; Sass et al., 1990, 1991a; Whiting and Chanton, 1993). The relationship of biomass to emission appears strongest with aboveground vegetative biomass prior to heading. This time coincides with the second of up to three seasonal emission maxima observed by other investigators (Holzapfel-Pschorr et al., 1986; Sass et al., 1990, 1991a; Schutz et al., 1991a; Yagi and Minami, 1990).
The slopes of the linear correlation between aboveground vegetative biomass and emission for individual cultivars, representing the increment of methane emission per gram biomass increment, are given in Table 14. The slopes range from 0.271 mg CH4 d$^{-1}$ g biomass$^{-1}$, for Labelle, to 1.196 mg CH4 $^{-1}$ g biomass $^{-1}$ for Della. In general, the slopes were slightly greater over the first 50 days past flood than to 63 or 73 days.

The dependence of emission on biomass, for all biomass categories, weakened when post-heading data were included. The number of significant and highly significant correlation coefficients decreased from 20 coefficients, through 50 days past flood, to 13 coefficients, through 73 days past flood. The categories affected most by this decline were aboveground dead biomass and total aboveground biomass as a result of panicle development and plant senescence.

The change in the relationship between aboveground live vegetative biomass and average daily emission during the season is illustrated in Figure 69 using Jasmine. Figure 69a shows both aboveground live vegetative biomass and average daily emissions for Jasmine during the season. When aboveground live biomass was correlated with emission for over 51 and 73 days, the correlation coefficient decreased from 0.816 to 0.324 (Figure 69b). Figures 70-74 show the relationship between aboveground live vegetative biomass and average daily emission over 63 days for all ten experimental cultivars.
Table 14. Slopes of Correlation Between Aboveground Live Vegetative Biomass and Emission

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>0 to 50 Days Past Flood</th>
<th>0 to 63 Days Past Flood</th>
<th>0 to 73 Days Past Flood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebonnet</td>
<td>0.610</td>
<td>0.626</td>
<td>0.774</td>
</tr>
<tr>
<td>Lemont</td>
<td>0.767</td>
<td>0.711</td>
<td>0.681</td>
</tr>
<tr>
<td>Dawn</td>
<td>0.402</td>
<td>0.426</td>
<td>0.437</td>
</tr>
<tr>
<td>Katy</td>
<td>0.564</td>
<td>0.600</td>
<td>0.658</td>
</tr>
<tr>
<td>Della</td>
<td>1.196</td>
<td>0.647</td>
<td>0.787</td>
</tr>
<tr>
<td>IR36</td>
<td>0.574</td>
<td>0.584</td>
<td>0.574</td>
</tr>
<tr>
<td>Mars</td>
<td>0.772</td>
<td>0.557</td>
<td>0.519</td>
</tr>
<tr>
<td>Brazos</td>
<td>0.675</td>
<td>0.564</td>
<td>0.558</td>
</tr>
<tr>
<td>Labelle</td>
<td>0.426</td>
<td>0.271</td>
<td>0.356</td>
</tr>
<tr>
<td>Jasmine</td>
<td>1.074</td>
<td>0.225</td>
<td>0.158</td>
</tr>
<tr>
<td>Average</td>
<td>0.706</td>
<td>0.521</td>
<td>0.550</td>
</tr>
</tbody>
</table>

*all data shown as mg CH4 / g biomass*
Figure 69a. Aboveground Live Vegetative Biomass and Methane Emission for Jasmine to 73 Days Past Flood

Figure 69b. Aboveground Live Vegetative Biomass and Methane Emission for Jasmine to 51 and 73 Days Past Flood

51 Day Period: \( y = 0.68x + 89.35 \), \( r = 0.82 \)

73 Day Period: \( y = 0.16x + 279.80 \), \( r = 0.32 \)
Figure 70a. Aboveground Live Biomass and Emission for Lebonnet to 63 Days Past Flood

\[ y = 0.63x - 18.36 \quad r = 0.92 \]

Figure 70b. Aboveground Live Biomass and Emission for Lemont to 63 Days Past Flood

\[ y = 0.71x - 37.30 \quad r = 0.96 \]
**Figure 71a.** Aboveground Live Biomass and Emission for Dawn to 63 Days Past Flood

\[ y = 0.43x + 89.08 \quad r = 0.88 \]

![Graph showing the relationship between aboveground live biomass (g/m²) and emission (mg/m²/day).](image)

**Figure 71b.** Aboveground Live Biomass and Emission for Katy to 63 Days Past Flood

\[ y = 0.60x - 0.39 \quad r = 0.95 \]

![Graph showing the relationship between aboveground live biomass (g/m²) and emission (mg/m²/day).](image)
Figure 72a. Aboveground Live Biomass and Emission for Della to 63 Days Past Flood

\[ y = 0.65x + 202.77 \quad r = 0.58 \]

Figure 72b. Aboveground Live Biomass and Emission for IR36 to 63 Days Past Flood

\[ y = 0.58x - 51.87 \quad r = 0.87 \]
Figure 73a. Aboveground Live Biomass and Emission for Mars to 63 Days Past Flood

\[ y = 0.56x + 160.31 \quad r = 0.68 \]

![Graph showing the relationship between aboveground live biomass and emission for Mars to 63 Days Past Flood. The graph includes a line of best fit with the equation \( y = 0.56x + 160.31 \) and a correlation coefficient \( r = 0.68 \).]

Figure 73b. Aboveground Live Biomass and Emission for Brazos to 63 Days Past Flood

\[ y = 0.56x - 17.49 \quad r = 0.89 \]

![Graph showing the relationship between aboveground live biomass and emission for Brazos to 63 Days Past Flood. The graph includes a line of best fit with the equation \( y = 0.56x - 17.49 \) and a correlation coefficient \( r = 0.89 \).]
Figure 74a. Aboveground Live Biomass and Emission for Labelle to 63 Days Past Flood

\[ y = 0.27x + 103.62 \quad r = 0.67 \]

Figure 74b. Aboveground Live Biomass and Emission for Jasmine to 63 Days Past Flood

\[ y = 0.22x + 265.00 \quad r = 0.42 \]
The degeneration of the relationship between biomass and methane during the season is supported by the results for emission and biomass trends, which were most consistent among cultivars until heading (Section 6.3). The period during which biomass-emission relationships were strongest, and trends were most similar, coincides with the vegetative-reproductive period. At this time, while the primary plant activity is production of vegetative and reproductive tissues, growth efficiency is high.

Growth efficiency represents the proportion of photosynthetic substrates converted to new plant organs (Yoshida, 1981). It is determined as the ratio between the amount of growth, or plant tissue, achieved (GR) and the total amount of substrate consumed during the growth period (GR+R). The difference between the total available substrates and the new growth is the estimated respiration (R) that provides the energy for biosynthesis and maintainance.

Growth efficiency decreases sharply after the milky stage of grain development, about 7 to 10 days past heading. Also at this time, as active filling declines and grain matures, the amount of energy derived from respiration for growth declines. Respiration processes and products are decreasingly directed toward production of new growth as the grain ripens. With rice plants, an observed decline in growth respiration of 61% was accompanied by a concurrent decrease in growth efficiency of 49% during the ripening period (Yamaguchi, 1978). While growth respiration appears to be
unaffected by temperature or plant species, maintenance respiration in temperature and species dependent (Yoshida, 1981).

The results of this study also suggest that the active growth of rice plants may be a stronger factor associated with methane emission than the processes of grain ripening. The biomass-emission correlation within cultivars and trends among cultivars are strongest and most similar during the period of highest plant growth efficiency. At the time of relatively uniform biomass and emission trends, plant growth efficiency is largely affected by processes of growth respiration which have low variability among plant species.

The early ripening phase, the time when the trends and relationships for biomass and emission appear to break down, coincides with a shift in respiration processes which results in decreased growth efficiency. The shift in metabolic activity from growth to maintenance respiration may affect changes in the production of intermediates that are important in methane production. Alternatively, the slowing of plant physical growth activity at this time may be a factor affecting biomass-emission relationships.

In general, correlations between aboveground live biomass and emission were weaker for rice varieties with extremely high biomass values and stronger for the cultivars with intermediate or low biomass. This suggests that while biomass, or plant growth, is an important factor in methane emission processes, the emissions of rice varieties with high biomass may be affected by other factors.
There may also be additional late season factors that affect methane emission as much, or more, than plant activity at this time. The amount of detrital material in floodwater and soil increases during the ripening stage due to the senescence of rice plants as well as other flora in the irrigation water and soil. As this material accumulates, the pool of organic substrates available for bacteria, including methanogens, increases. The location and magnitude of additional organic sources in late season may be random and, thus, the methane emission trends during the ripening phase vary among cultivars (Fisher, personal communication).

6.7 Biomass and Methane Emission Among Cultivars

The relationship between biomass and emission among cultivars appeared sensitive to the developmental rates of rice varieties and the comparison among cultivars was strongest before heading when it included developmentally equivalent plants. In order to compare biomass-emission relationships among cultivars, data for aboveground live vegetative biomass and daily methane emission were plotted for all 1993 and 1994 cultivars during their individual vegetative (flooding to panicle differentiation), reproductive (panicle differentiation to heading) and active filling (heading to heading + 14 days) stages. Interpolated estimates of aboveground live vegetative biomass and emission on the observed
date of panicle differentiation, heading and active filling of each cultivar were also compared among cultivars.

Figure 75 shows aboveground live vegetative biomass and daily methane emissions for all cultivars between flooding and panicle differentiation. Methane emissions, which begin clustered near zero, become more variable as biomass grows larger. The positive relationship between biomass and emissions that is suggested by the data is affected by the increasing variability in emission and lacks significance if the cluster of low emission data is excluded from the analysis.

The data in Figure 75 can be grouped within the two emission groups produced using median differences (Figure 68). Highly significant linear correlations result between aboveground live vegetative biomass and daily emission during the vegetative stage of the rice plants (Figure 76). The slopes of the lines describing the correlations within the two groups, 0.487 mg CH$_4$ d$^{-1}$ g biomass$^{-1}$ for low emitting cultivars and 1.085 mg CH$_4$ d$^{-1}$ g biomass$^{-1}$ for high emitting cultivars, differ by a factor of 2.23. Due to its performance during the vegetative period, Jasmine groups with the high emitting cultivars, although its total seasonal emissions were within the low emission group.

When emission data near zero are excluded from the correlation, the results show two emission groups with linear correlations that are parallel to each other (Figure 77). The correlation remains highly significant for the low emitting cultivars
Figure 75. 1993 and 1994 Aboveground Live Vegetative Biomass and Daily Emission To Particle Differentiation (1994 Data: Huong, Y.)
Figure 76. 1993 and 1994 Aboveground Live Vegetative Biomass and Daily Emission To Panicle Differentiation (1994 Data: Huong, Y.)

Low Emitting Cultivars: $y = 0.49x - 20.69$, $r = 0.89^{**}$
High Emitting Cultivars: $y = 1.09x - 30.49$, $r = 0.89^{**}$

Low Emitting Cultivars
- Lemont 94
- Labelle 94
- Lebonnet 93
- Lemont 93
- Dawn 93
- Katy 93
- IR36
- Brazos 93
- Labelle 93

High Emitting Cultivars
- Mars 94
- Delia 93
- Mars 93
- Jasmine 93
Figure 77. 1993 and 1994 Aboveground Live Vegetative Biomass (Greater Than 200 g m⁻²) and Daily Emission To Panicle Differentiation (1994 Data: Huong, Y., unpublished)

\[
y = 0.42x + 21.11 \quad r = 0.66^* (p=0.01) \quad \text{Low-Emitting Cultivars}
\]

\[
y = 0.34x + 329.54 \quad r = 0.72 \quad \text{High-Emitting Cultivars}
\]
and, due to limited data, is very near the 5% probability for the high emission cultivars. The only difference in data for the two groups is an abrupt increase in emission for high-emitting cultivars, between 14 and 30 days past flood, which resulted in a y-intercept difference of 308.43 mg CH₄ d⁻¹ g biomass⁻¹ between the two groups. The slopes of the correlation between biomass and emission after 30 days past flood for low and high emitting cultivars were 0.402 mg CH₄ d⁻¹ g biomass⁻¹ and 0.336 mg CH₄ d⁻¹ g biomass⁻¹, respectively. The apparent sharp increase in emission among high-emitting cultivars may be related to a biomass threshold necessary to emit significantly more methane, microbial population growth or soil Eh factors.

The interpolated values for aboveground live vegetative biomass and methane emission at panicle differentiation are plotted for each cultivar in 1993 and 1994 in Figure 78. A highly significant correlation coefficient, 0.917**, results among the members of the low emission group and a nonsignificant coefficient, 0.791, is produced for the high group. The results for the high emission group were affected by a low number of data.

At panicle differentiation, the data for the two emission groups show two important relationships. First, a similar association is present among members within each group. The slopes of the correlations for each group are very similar. The slopes, representing the increment of methane emission per increment gram biomass, are 0.39 mg CH₄ d⁻¹ g biomass⁻¹ and 0.43 mg CH₄ d⁻¹ g biomass⁻¹ for the low and high emission group, respectively.
Figure 78. 1993 and 1994 Aboveground Live Vegetative Biomass and Methane Emission at Panicle Differentiation (1994 Data: Huong, Y., unpublished)

- Group I: $y = 0.39x + 48.18$, $r = 0.92**$
- Group II: $y = 0.43x + 381.28$, $r = 0.79$
Second, members of the two groups with equivalent biomass differ in emissions by approximately 330 mg CH$_4$ d$^{-1}$ at the end of the vegetative stage. It is important to note that, although the median mature aboveground live vegetative biomass of Mars differed significantly between 1993 and 1994, its biomass and biomass-emission relationship at the end of the first developmental period were similar for both years. Its growth may have slowed later in the season, perhaps due to environmental or management factors.

The 1993 and 1994 aboveground live vegetative biomass and daily methane emission data between panicle differentiation and heading for all cultivars are shown in Figure 79. The correlation coefficients between these two parameters are 0.594* and 0.256 for the low and high emission group, respectively. The significance of the coefficients for each group is affected by increased variability within the emission groups. When Jasmine is excluded from the high emission group, the correlation coefficient increases to 0.551 but remains nonsignificant.

The slopes of the linear correlations within the two emission groups are parallel to each other during the reproductive stage, panicle differentiation to heading, just as they were after 30 days past flood during the vegetative stage (Figure 77). The slopes of the correlations for low and high emitting cultivars are 0.309 mg CH$_4$ d$^{-1}$ g biomass$^{-1}$ and 0.279 mg CH$_4$ d$^{-1}$ g biomass$^{-1}$, respectively. These slopes during this developmental stage are slightly lower and closer in value than slopes in the first period. The increasing
Figure 79. 1993 and 1994 Aboveground Live Vegetative Biomass and Daily Emission From Panicle Differentiation to Heading for Ten Cultivars (1994 Data: Huong, Y., unpublished)

Low Emitting Cultivars: $y = 0.31x + 176.81$, $r = 0.59*$

High Emitting Cultivars: $y = 0.28x + 579.52$, $r = 0.26$

Low Emitting Cultivars
- Lemont 94
- Labelle 94
- Lebonnet 93
- Lemont 93
- Dawn 93
- Katy 93
- IR36 93
- Brazos 93
- Labelle 93

High Emitting Cultivars
- Mars 94
- Della 93
- Mars 93
- Jasmine 93
similarity between the slopes for the low and high emission groups may reflect the decreasing variation observed over the season in emissions among cultivars (Section 6.3).

Aboveground live vegetative biomass and daily emission data collected during active filling, from heading to two weeks after heading, are given for all cultivars in Figure 80. It is apparent that the high and low emission group trends, which were present through heading, are not evident in late season. Methane emissions at this time are often variable and difficult to predict. From this figure and Figure 81, which shows interpolated biomass and emission at filling, methane emission either lacks dependence on the aboveground live vegetative biomass during grain ripening or is affected by additional factors at this time.

The results of the comparison between aboveground live vegetative biomass and emissions among cultivars support the observed biomass-emission trends within individual cultivars. The relationship between aboveground live vegetative biomass and methane emissions is complex and appears strongly associated with plant development prior to heading. Like biomass and emission within cultivars, the relationship between plant growth and methane emission among cultivars weakens after the reproductive phase of the plant when increased variability in emission is present.

The relationship between biomass and emission may be related to the translocation of carbohydrates from sources to sinks within the plant. If aboveground biomass represents a surrogate for root
Figure 80. 1993 and 1994 Aboveground Live Vegetative Biomass and Daily Emission From Heading to Filling For Ten Cultivars (1994 Data: Huong, Y., unpublished)

**Low Emitting Cultivars**
- □ Lemont 94
- ◊ Labelle 94
- ◮ Lebonnet 93
- △ Lemont 93
- ■ Dawn 93
- ◊ Katy 93
- ⊳ IR36 93
- ▼ Brazos 93
- ◼ Labelle 93

**High Emitting Cultivars**
- ★ Mars 94
- ▲ Della 93
- ★ Mars 93
- ◊ Jasmine 93
Figure 81. 1993 and 1994 Aboveground Live Vegetative Biomass and Daily Emission at Filling for Ten Cultivars (1994 Data: Huong, Y., unpublished)
biomass, as suggested by the correlation between the two, then methane emission may result from processes of root exudation and sloughing. The uniformity of the association of emission and plant growth among cultivars suggests that the dependence of emission on aboveground live vegetative biomass is related to processes that are similar among cultivar groups, even though the cultivars differ in absolute levels of emissions.

Results from this study show methane emissions among cultivars vary by more than a factor of two. For example, the total seasonal emission for the highest emitting cultivar, Della, was 2.43 times greater than the lowest emitting cultivar, Labelle. The highest and lowest average daily emission varied among cultivars by a factor of 2.27.

The two emission groups, determined by emission differences during the reproductive stage, also appear to be related by factors between 1.8 and 2.06. The cumulative emissions of the low and high-emitting cultivars were related through 30, 51 and 64 days past flood by factors of 2.14, 2.06 and 1.92, respectively. The slope of cumulative emission for high-emitting cultivars, 0.395 g CH₄ d⁻¹, was 1.8 time greater than the cumulative emission slope of the low emission group, 0.710 g CH₄ d⁻¹.

The effects of cultivar differences observed in this study appear to be in agreement with the results from two similar studies which also observed differences in emission among cultivars (Erda, 1993; Parashar, 1992). Methane emission differences are not fully
explained by differences in plant biomass, but the data suggest that methane emission is related to plant biomass, especially until heading. Biomass may be an integrating variable which reflects a number of important factors such as differences in the photosynthetic efficiency, translocation processes of photosynthates from leaves to various sinks, exudation of different cultivars and the effectiveness of gas transport tissue among cultivars (Whiting and Chanton, 1993).

Since the cultivars in this study developed at different rates, some of the variation in plant biomass, as well as methane emissions, among cultivars may be related to the environmental conditions experienced by these various stages. Heading ± 21 days is a critical period during which sunlight can significantly impact yield (Stansel, 1975). If photosynthetic activity, due to climate, is higher during this period, then more photosynthates are potentially available for biomass, storage and, through exudation, methanogenesis.

The period of heading among the ten cultivars in 1993, 39-57 days past flood, spanned almost three weeks. Since the so-called critical period extended 20 days before and after that, photosynthetic activity was sensitive to climate for at least one of the cultivars for a total of about 60 days. At this time, the mean air temperature rose from approximately 30 to 36°C while the mean soil temperature remained constant at about 25°C. Water levels ranged from 5 to 12 cm across fields. Methane emissions have been found to decrease with decreases in solar radiation and floodwater (Sass, et al., 1991b, 1992).
6.8 Biomass and Grain Yield Among Cultivars

A comparison of panicle biomass weight at 73 days past flood and grain yield, determined by staff of Texas A&M Agricultural Research Station, is shown in Figure 82. The correlation between panicle biomass weight and grain yield was highly significant among nine of the ten cultivars. The correlation coefficient among ten cultivars, 0.255, increased to 0.781**, among nine, when the cultivar, IR36, was excluded. The grain yield of IR36 was unusually high when compared to its panicle biomass weight at 73 days past flood, 5 days prior to harvest. No discrepancies were reported in the determination of the grain yield for IR36 by staff at the Texas A&M Agricultural Research Station.

The harvest index for each cultivar is given in Table A4. The harvest index is the dry grain yield expressed as a percentage of the total dry weight and it represents the proportion of photosynthetic product allocated to grain. Every cultivar possesses a characteristic harvest index, which typically ranges between 0.3 and 0.5.

Harvest indexes for the ten experimental cultivars in this study showed little variation with one exception (Figure 83). Nine of the ten harvest indexes were determined to be between 0.304 and 0.408. The harvest index for IR36 was 0.63 and may have been affected by its reported high grain yield.
Figure 82a. Panicle Biomass at 73 Days Past Flood and Grain Yield

\[ y = 0.21x + 493.77 \quad r = 0.26 \]

Figure 82b. Panicle Biomass at 73 Days Past Flood and Grain Yield (exc.IR36)

\[ y = 0.64x + 142.23 \quad r = 0.78** \]
Figure 83. Harvest Index for Ten Cultivars
6.9 Biomass, Emission and Grain Yield Within and Among Cultivars

Relationships between biomass, emission and grain yield have been suggested by previous research (Sass et al., 1991). The photosynthetic activity of vegetative biomass affects the pool of organic carbon available for the production of both methane and grain. This relationship may be especially important during the ripening period when carbohydrates are translocated from storage locations in the plant to the panicles in order to fill grain.

The relationship between emission and yield is evident when it is examined on the level of the individual plant. Emission at filling (heading plus 14 days) did not correlate with yield when both parameters were expressed in terms of area (g m\(^{-2}\)). However, important relationships were suggested by the data when the cultivar emission at filling and yield were first normalized to aboveground live vegetative biomass at filling.

Figure 84 shows both methane emitted and grain produced per gram aboveground live vegetative biomass for each cultivar. When emission per aboveground live vegetative biomass is plotted against grain yield per aboveground live biomass, a significant correlation coefficient of 0.633 results (Figure 85a). A highly significant relationship, \( r=0.926 \), results when IR36, an outlier with an unusually high harvest index, is not considered in the analysis (Figure 85b). Two important relationships among cultivars are suggested by these three figures.
Figure 84. Grain Yield Per Gram Aboveground Live Vegetative Biomass and Daily Emission Per Gram Aboveground Live Vegetative Biomass at Filling
Figure 85a. Grain Yield and Daily Emission Per Gram
Aboveground Live Vegetative Biomass at Filling

\[ y = 0.35x + 0.24 \quad r = 0.63^* \]

Figure 85b. Grain Yield and Daily Emission Per Gram Aboveground Live Vegetative Biomass at Filling (excluding IR36)

\[ y = 0.69x + 0.00 \quad r = 0.93^{**} \]
First, the amount of methane emitted by the rice plant relative to the amount of grain produced, within a cultivar, is consistent among cultivars. The average for the ten cultivars is 0.66 mg CH$_4$ g grain$^{-1}$ (standard deviation=0.11 mg CH$_4$ g grain$^{-1}$). When IR36, with its questionably high yield is excluded, the average for the remaining nine cultivars is 0.67 mg CH$_4$ g grain$^{-1}$ (standard deviation =0.07 mg CH$_4$ g grain$^{-1}$).

These data suggest that similar processes of carbon allocation may occur among cultivars and result in a relatively constant ratio of emission to yield during filling. Approximately 0.07% of grain weight produced per gram aboveground live biomass is emitted by the rice plant as methane. The plants appear to be drawing upon their pool of photosynthates through a uniform process. Although a causative relationship is not implicit, it appears that emission and yield may have a consistent relationship to aboveground live vegetative tissue and each other that is present across cultivars.

The second relationship among cultivars suggested by Figures 84 and 85 is the variability in the apparent pool of translocatable carbon. Comparisons between the ten cultivars show that, although methane and grain are present proportionally within all cultivars, the amount of methane per gram aboveground live vegetative biomass and grain per gram aboveground live vegetative biomass varies among them. Katy, which represents the maximum per gram biomass observed for both emission and yield, emitted 0.74 mg CH$_4$ g aboveground live biomass$^{-1}$ and produced 1.06 g grain g
aboveground live biomass\(^{-1}\). The lowest values were associated with Jasmine. Jasmine emitted 0.32 mg CH\(_4\) g aboveground live biomass\(^{-1}\) and produced 0.520 g grain gram aboveground live biomass \(^{-1}\). The ratios of emission to yield for Katy and Jasmine were 7 x 10\(^{-4}\) and 6.2 x 10\(^{-4}\), respectively. Although Jasmine emitted less methane per gram aboveground live biomass than Katy, overall, it had a higher seasonal flux because of its larger amount of biomass per square meter.

The performance of cultivars with respect to emission and grain yield in 1994 was similar to 1993 (Figure 86). When the emission per gram aboveground live vegetative biomass of all 1993 and 1994 cultivars is compared to the yield per gram aboveground live vegetative biomass, a highly significant correlation results. The per gram biomass ratio of emission to yield of Mars in 1994, 1.25, was slightly higher than most in 1993. This was related to the very low aboveground live vegetative biomass observed for Mars in 1994. The ratios of the remaining 1994 cultivars were very comparable to those in 1993.

The differences in the amount of photosynthate available during ripening for methane emission and grain filling does not appear to be a function of the amount of aboveground live vegetative biomass produced by a cultivar. Cultivars of approximately the same biomass seem to have different potentials for photosynthate production.

\[ y = 0.82x - 0.06 \quad r = 0.66^{**} \]
6.10 Root Porosity and Relative Chlorophyll

Within cultivars, root porosity and relative chlorophyll did not correlate with either the growth of aboveground live vegetative biomass or average daily emissions during the season. Among cultivars, when root porosity was compared with aboveground live biomass at heading and cumulative emission to heading, no relationship was suggested (Figure 87). The same results among cultivars occurred with relative chlorophyll, biomass and emission (Figure 88).

These results suggest three possibilities. First, both root porosity and chlorophyll are unrelated to aboveground live vegetative biomass and emission. Or, if a relationship exists, it may not be simple or direct. Second, the variability resulting from the determination of root porosity and chlorophyll prohibited meaningful analysis of the relationship between these parameters, biomass and methane emission. In this case, additional root porosity and relative chlorophyll data is necessary. Third, if root porosity is, in fact, unrelated to methane emission, either an alternative mechanism exists for methane emission or an earlier step in the process of methane production and emission may be limiting production and affecting the observed varietal emission differences. Differences in available substrates, perhaps associated with root growth or root morphology, may produce differences in methane production which result in emission differences among cultivars.
Figure 87a. Root Porosity and Daily Emission on Heading

Figure 87b. Aboveground Live Vegetative Biomass and Root Porosity on Heading
Figure 88a. Relative Chlorophyll and Daily Emission on Heading

Figure 88b. Relative Chlorophyll and Aboveground Live Vegetative Biomass on Heading
These possibilities are also supported by the qualitative observations made of roots and aerenchyma tissue in the stem during the season.

6.11 Conclusions

This study involved ten different cultivars of rice grown during one season. Total seasonal emissions varied between the highest and lowest emitting cultivars by a factor of 2.4. Early emission values were predictive of later emission. There were significant differences in total seasonal methane emission among rice varieties which resulted in two emission groups. The average slopes for the total cumulative emissions of the high-emitting cultivar group was 1.8 times greater than the average slope of the low-emitting group. The range of emissions within the low emission group was greater than in the higher group. The differences in total seasonal methane did not coincide with significant differences in mature aboveground live vegetative biomass.

The relationship between rice plant biomass and methane emission was complex and, although a relationship between biomass and methane emission was indicated by data, it may not be simple or direct. The dependence of methane on biomass was strong until heading within cultivars and among developmentally equivalent cultivars in both emission groups. During the vegetative growth period, methane emission and aboveground live vegetative biomass were related within individual cultivars, among low-emitting
cultivars, and among high-emitting cultivars with biomass greater than 200 g m$^{-2}$. The slopes for biomass-emission correlations suggested that cultivars within emission groups emitted methane per biomass proportionally and that differences among the two groups resulted from factors present in the system between 14 and 30 days past flood.

Incongruency in emission and biomass data was also present in the data. Emission differences were consistent among years, although biomass differences varied significantly. Emission data were more variable than biomass data and trends of variation in emission and biomass were reciprocal. Maximum variability in emission was observed prior to heading when biomass among cultivars was most similar. Conversely, the greatest biomass differences occurred after heading at the time emission among the varieties became less varied. Although there is a relationship between rice growth and development and methane emission, the results of this study strongly suggest that biomass may be the major plant parameter which is coupled to other factors more directly involved in methane production and emission.

The relationship between aboveground live vegetative biomass of rice and methane emission appeared to be coupled to the early, efficient growth of plants until heading or shortly afterwards. This period of plant development does not coincide with the existing divisions of plant growth described in the three and two phase models (Figure 1). A two phase model, subdivided at the heading-
milky grain interface and consisting of the active growth stage and senescence stage, or growth respiration stage and maintenance respiration stage, would more accurately represent the development of the rice plant as it relates to methane production and emission.

In addition, during ripening, methane emission appeared consistently proportional to grain production among cultivars, when determined per gram biomass, and may be related through processes of carbohydrate partitioning. Root porosity was not associated with observed trends or differences in emission or biomass and did not appear to be a limiting factor in methane emission.
BIBLIOGRAPHY


Hurlbert, Stuart H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54(2) 187-211.


<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Days</th>
<th>Aboveground</th>
<th>Root</th>
<th>Root (0-10 cm)</th>
<th>Root (0-5 cm)</th>
<th>Root (0-5 cm)</th>
<th>Root (5-10 cm)</th>
<th>Root (5-10 cm)</th>
<th>Root Shoot</th>
<th>Total</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebanon</td>
<td>16</td>
<td>60.72</td>
<td>3.93</td>
<td>11.45</td>
<td>7.50</td>
<td>3.93</td>
<td>0.18</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>620.48</td>
<td>3.93</td>
<td>11.45</td>
<td>7.50</td>
<td>3.93</td>
<td>0.18</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>689.82</td>
<td>3.93</td>
<td>11.45</td>
<td>7.50</td>
<td>3.93</td>
<td>0.18</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>634.05</td>
<td>3.93</td>
<td>11.45</td>
<td>7.50</td>
<td>3.93</td>
<td>0.18</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>641.77</td>
<td>3.93</td>
<td>11.45</td>
<td>7.50</td>
<td>3.93</td>
<td>0.18</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemont</td>
<td>16</td>
<td>74.88</td>
<td>5.86</td>
<td>11.74</td>
<td>11.70</td>
<td>0.04</td>
<td>11.70</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>355.10</td>
<td>5.86</td>
<td>11.74</td>
<td>11.70</td>
<td>0.04</td>
<td>11.70</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>578.08</td>
<td>5.86</td>
<td>11.74</td>
<td>11.70</td>
<td>0.04</td>
<td>11.70</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>797.87</td>
<td>5.86</td>
<td>11.74</td>
<td>11.70</td>
<td>0.04</td>
<td>11.70</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>551.24</td>
<td>5.86</td>
<td>11.74</td>
<td>11.70</td>
<td>0.04</td>
<td>11.70</td>
<td>76.09</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dawn</td>
<td>16</td>
<td>54.35</td>
<td>3.64</td>
<td>10.28</td>
<td>6.91</td>
<td>3.37</td>
<td>0.19</td>
<td>68.27</td>
<td>3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>357.23</td>
<td>3.64</td>
<td>10.28</td>
<td>6.91</td>
<td>3.37</td>
<td>0.19</td>
<td>68.27</td>
<td>3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>538.56</td>
<td>3.64</td>
<td>10.28</td>
<td>6.91</td>
<td>3.37</td>
<td>0.19</td>
<td>68.27</td>
<td>3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>1159.89</td>
<td>3.64</td>
<td>10.28</td>
<td>6.91</td>
<td>3.37</td>
<td>0.19</td>
<td>68.27</td>
<td>3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>938.04</td>
<td>3.64</td>
<td>10.28</td>
<td>6.91</td>
<td>3.37</td>
<td>0.19</td>
<td>68.27</td>
<td>3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katy</td>
<td>16</td>
<td>60.08</td>
<td>3.50</td>
<td>10.68</td>
<td>10.64</td>
<td>0.04</td>
<td>10.64</td>
<td>74.27</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>353.92</td>
<td>3.50</td>
<td>10.68</td>
<td>10.64</td>
<td>0.04</td>
<td>10.64</td>
<td>74.27</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>550.47</td>
<td>3.50</td>
<td>10.68</td>
<td>10.64</td>
<td>0.04</td>
<td>10.64</td>
<td>74.27</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>650.29</td>
<td>3.50</td>
<td>10.68</td>
<td>10.64</td>
<td>0.04</td>
<td>10.64</td>
<td>74.27</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>667.61</td>
<td>3.50</td>
<td>10.68</td>
<td>10.64</td>
<td>0.04</td>
<td>10.64</td>
<td>74.27</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Della</td>
<td>16</td>
<td>95.43</td>
<td>5.86</td>
<td>17.72</td>
<td>10.90</td>
<td>6.82</td>
<td>0.18</td>
<td>115.02</td>
<td>5.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>411.75</td>
<td>5.86</td>
<td>17.72</td>
<td>10.90</td>
<td>6.82</td>
<td>0.18</td>
<td>115.02</td>
<td>5.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>452.54</td>
<td>5.86</td>
<td>17.72</td>
<td>10.90</td>
<td>6.82</td>
<td>0.18</td>
<td>115.02</td>
<td>5.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>1029.13</td>
<td>5.86</td>
<td>17.72</td>
<td>10.90</td>
<td>6.82</td>
<td>0.18</td>
<td>115.02</td>
<td>5.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>923.95</td>
<td>5.86</td>
<td>17.72</td>
<td>10.90</td>
<td>6.82</td>
<td>0.18</td>
<td>115.02</td>
<td>5.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not Available, All data are g/m²

APPENDIX
Table A1 (II). Summary of Seasonal Biomass Partitioning for Samples 1, 2, 4, 6 and 7

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Days</th>
<th>Aboveground</th>
<th>Root Crown</th>
<th>Root (0-10 cm)</th>
<th>Root (0-5 cm)</th>
<th>Root (5-10 cm)</th>
<th>Root Shoot (0-10 cm)</th>
<th>Total</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR36</td>
<td>16</td>
<td>124.69</td>
<td>0.00</td>
<td>10.98</td>
<td>21.80</td>
<td>16.97</td>
<td>4.83</td>
<td>157.37</td>
<td>6.30</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>507.54</td>
<td>0.00</td>
<td>40.96</td>
<td>57.99</td>
<td>89.95</td>
<td>NA</td>
<td>606.39</td>
<td>9.88</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>390.56</td>
<td>0.00</td>
<td>22.42</td>
<td>59.50</td>
<td>26.57</td>
<td>32.93</td>
<td>472.48</td>
<td>16.61</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>589.34</td>
<td>2.19</td>
<td>32.71</td>
<td>92.66</td>
<td>80.21</td>
<td>12.45</td>
<td>930.89</td>
<td>52.86</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>703.87</td>
<td>27.00</td>
<td>47.52</td>
<td>160.67</td>
<td>141.77</td>
<td>18.89</td>
<td>1158.62</td>
<td>123.80</td>
</tr>
<tr>
<td>Mars</td>
<td>16</td>
<td>129.36</td>
<td>0.00</td>
<td>15.07</td>
<td>18.65</td>
<td>11.00</td>
<td>7.65</td>
<td>163.08</td>
<td>5.70</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>417.81</td>
<td>0.00</td>
<td>25.66</td>
<td>41.76</td>
<td>33.62</td>
<td>8.15</td>
<td>485.23</td>
<td>16.38</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>871.78</td>
<td>66.48</td>
<td>40.99</td>
<td>91.64</td>
<td>56.53</td>
<td>35.12</td>
<td>1070.85</td>
<td>45.07</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>916.94</td>
<td>596.01</td>
<td>60.50</td>
<td>119.17</td>
<td>73.00</td>
<td>46.16</td>
<td>1602.92</td>
<td>97.89</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>848.91</td>
<td>633.37</td>
<td>50.55</td>
<td>116.19</td>
<td>80.26</td>
<td>35.83</td>
<td>1685.42</td>
<td>136.99</td>
</tr>
<tr>
<td>Brazos</td>
<td>16</td>
<td>67.16</td>
<td>0.00</td>
<td>6.64</td>
<td>10.93</td>
<td>9.12</td>
<td>1.81</td>
<td>84.73</td>
<td>3.51</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>360.81</td>
<td>0.00</td>
<td>28.17</td>
<td>38.75</td>
<td>48.66</td>
<td>NA</td>
<td>427.72</td>
<td>8.23</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>589.75</td>
<td>0.00</td>
<td>34.83</td>
<td>76.13</td>
<td>58.03</td>
<td>18.10</td>
<td>700.71</td>
<td>25.63</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>793.81</td>
<td>276.41</td>
<td>48.12</td>
<td>96.54</td>
<td>67.70</td>
<td>28.84</td>
<td>1214.88</td>
<td>49.24</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>626.42</td>
<td>561.83</td>
<td>37.15</td>
<td>112.57</td>
<td>80.84</td>
<td>31.74</td>
<td>1339.98</td>
<td>125.79</td>
</tr>
<tr>
<td>Labelle</td>
<td>16</td>
<td>89.31</td>
<td>0.00</td>
<td>6.50</td>
<td>15.01</td>
<td>14.99</td>
<td>0.03</td>
<td>110.82</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>371.09</td>
<td>0.00</td>
<td>16.81</td>
<td>52.16</td>
<td>27.18</td>
<td>24.98</td>
<td>440.06</td>
<td>7.52</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>739.36</td>
<td>141.12</td>
<td>25.75</td>
<td>72.11</td>
<td>56.98</td>
<td>15.53</td>
<td>998.34</td>
<td>23.98</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>963.47</td>
<td>504.30</td>
<td>62.73</td>
<td>134.08</td>
<td>79.04</td>
<td>55.03</td>
<td>1664.58</td>
<td>105.65</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>860.30</td>
<td>343.56</td>
<td>47.34</td>
<td>134.77</td>
<td>77.40</td>
<td>57.36</td>
<td>1385.66</td>
<td>75.50</td>
</tr>
<tr>
<td>Jasmine</td>
<td>16</td>
<td>68.14</td>
<td>0.00</td>
<td>6.69</td>
<td>14.24</td>
<td>9.15</td>
<td>5.09</td>
<td>89.07</td>
<td>6.73</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>277.35</td>
<td>0.00</td>
<td>22.79</td>
<td>36.73</td>
<td>34.84</td>
<td>NA</td>
<td>326.87</td>
<td>10.98</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>642.47</td>
<td>0.00</td>
<td>41.76</td>
<td>91.82</td>
<td>122.72</td>
<td>NA</td>
<td>776.04</td>
<td>39.31</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>1284.94</td>
<td>263.54</td>
<td>82.46</td>
<td>165.93</td>
<td>121.58</td>
<td>44.35</td>
<td>1796.87</td>
<td>112.04</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1058.10</td>
<td>415.08</td>
<td>67.51</td>
<td>171.85</td>
<td>133.29</td>
<td>38.56</td>
<td>1673.55</td>
<td>134.60</td>
</tr>
</tbody>
</table>

NA=Not Available, All data are g/m²
Table A2. Summary of Seasonal Biomass Partitioning
for Samples 3, 5 and 8

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Days</th>
<th>Aboveground</th>
<th>Live Vegetative</th>
<th>Panicle</th>
<th>Aboveground</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Past Flood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lebonnet</td>
<td>32</td>
<td>629.45</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>782.94</td>
<td>135.18</td>
<td>71.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>662.09</td>
<td>723.55</td>
<td>182.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemont</td>
<td>32</td>
<td>565.59</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>737.15</td>
<td>192.87</td>
<td>33.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>643.82</td>
<td>849.81</td>
<td>175.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dawn</td>
<td>32</td>
<td>655.97</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>989.25</td>
<td>30.40</td>
<td>55.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>1005.19</td>
<td>837.65</td>
<td>245.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katy</td>
<td>32</td>
<td>576.34</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>854.63</td>
<td>179.40</td>
<td>52.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>665.56</td>
<td>903.30</td>
<td>190.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Della</td>
<td>32</td>
<td>646.05</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>942.02</td>
<td>70.97</td>
<td>132.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>618.63</td>
<td>654.12</td>
<td>198.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR36</td>
<td>32</td>
<td>598.42</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>991.76</td>
<td>17.22</td>
<td>59.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>619.47</td>
<td>563.08</td>
<td>213.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>32</td>
<td>624.14</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>861.51</td>
<td>243.35</td>
<td>63.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>698.81</td>
<td>943.92</td>
<td>154.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazos</td>
<td>32</td>
<td>604.27</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>721.48</td>
<td>89.43</td>
<td>26.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>533.06</td>
<td>676.05</td>
<td>122.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labelle</td>
<td>32</td>
<td>630.99</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>694.30</td>
<td>303.87</td>
<td>50.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>792.01</td>
<td>702.92</td>
<td>148.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jasmine</td>
<td>32</td>
<td>536.00</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>831.71</td>
<td>0.00</td>
<td>39.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>839.47</td>
<td>672.14</td>
<td>89.08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA=Not Available, All data are g/m²
Table A3(I). Average Daily Emission On Days of Biomass Collection.

<table>
<thead>
<tr>
<th>Days Past Flood</th>
<th>Lebonnet</th>
<th>Lemont</th>
<th>Dawn</th>
<th>Katy</th>
<th>Della</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>15.20</td>
<td>16.34</td>
<td>23.72</td>
<td>29.09</td>
<td>31.24</td>
</tr>
<tr>
<td>30</td>
<td>286.80</td>
<td>204.90</td>
<td>268.59</td>
<td>250.13</td>
<td>451.60</td>
</tr>
<tr>
<td>32</td>
<td>315.39</td>
<td>300.87</td>
<td>300.30</td>
<td>279.76</td>
<td>556.85</td>
</tr>
<tr>
<td>43</td>
<td>448.38</td>
<td>448.75</td>
<td>440.46</td>
<td>370.21</td>
<td>883.37</td>
</tr>
<tr>
<td>51</td>
<td>474.18</td>
<td>528.97</td>
<td>456.32</td>
<td>496.40</td>
<td>1151.04</td>
</tr>
<tr>
<td>63</td>
<td>426.91</td>
<td>486.25</td>
<td>581.29</td>
<td>479.89</td>
<td>456.71</td>
</tr>
<tr>
<td>70</td>
<td>1097.70</td>
<td>392.21</td>
<td>631.96</td>
<td>366.51</td>
<td>1156.07</td>
</tr>
<tr>
<td>73</td>
<td>430.47</td>
<td>312.15</td>
<td>439.76</td>
<td>665.85</td>
<td>695.87</td>
</tr>
</tbody>
</table>

Table A3(II). Average Daily Emission On Days of Biomass Collection.

<table>
<thead>
<tr>
<th>Days Past Flood</th>
<th>IR36</th>
<th>Mars</th>
<th>Brazos</th>
<th>Labelle</th>
<th>Jasmine</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>14.35</td>
<td>40.66</td>
<td>16.62</td>
<td>20.24</td>
<td>20.64</td>
</tr>
<tr>
<td>30</td>
<td>136.80</td>
<td>570.31</td>
<td>141.07</td>
<td>318.32</td>
<td>366.04</td>
</tr>
<tr>
<td>32</td>
<td>185.55</td>
<td>711.65</td>
<td>288.52</td>
<td>334.55</td>
<td>472.98</td>
</tr>
<tr>
<td>43</td>
<td>305.40</td>
<td>723.35</td>
<td>436.52</td>
<td>367.42</td>
<td>715.00</td>
</tr>
<tr>
<td>51</td>
<td>564.54</td>
<td>626.54</td>
<td>443.33</td>
<td>272.05</td>
<td>485.47</td>
</tr>
<tr>
<td>63</td>
<td>350.29</td>
<td>416.96</td>
<td>337.64</td>
<td>260.05</td>
<td>348.35</td>
</tr>
<tr>
<td>70</td>
<td>316.40</td>
<td>536.14</td>
<td>319.70</td>
<td>381.30</td>
<td>331.15</td>
</tr>
<tr>
<td>73</td>
<td>356.32</td>
<td>708.60</td>
<td>399.66</td>
<td>583.42</td>
<td>371.70</td>
</tr>
</tbody>
</table>
Table A4. Grain Yield With Standard Deviation and Harvest Index.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Yield (g/m²)</th>
<th>Standard Deviation</th>
<th>Harvest Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebonnet</td>
<td>604.55</td>
<td>53.59</td>
<td>0.38</td>
</tr>
<tr>
<td>Lemont</td>
<td>731.48</td>
<td>64.87</td>
<td>0.40</td>
</tr>
<tr>
<td>Dawn</td>
<td>707.93</td>
<td>62.01</td>
<td>0.35</td>
</tr>
<tr>
<td>Katy</td>
<td>685.45</td>
<td>51.16</td>
<td>0.36</td>
</tr>
<tr>
<td>Della</td>
<td>624.86</td>
<td>70.99</td>
<td>0.36</td>
</tr>
<tr>
<td>IR36</td>
<td>808.05</td>
<td>69.50</td>
<td>0.63</td>
</tr>
<tr>
<td>Mars</td>
<td>730.57</td>
<td>53.86</td>
<td>0.40</td>
</tr>
<tr>
<td>Brazos</td>
<td>597.14</td>
<td>37.76</td>
<td>0.41</td>
</tr>
<tr>
<td>Labelle</td>
<td>466.66</td>
<td>9.35</td>
<td>0.32</td>
</tr>
<tr>
<td>Jasmine</td>
<td>550.84</td>
<td>35.63</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Table A5. 1994 Emission and Biomass for Lemont, Mars and Labelle.

Emission given in g/m2/d. Biomass given in g/m2.

<table>
<thead>
<tr>
<th>Lemont</th>
<th>Days Past Flood</th>
<th>Aboveground Live</th>
<th>Total Aboveground</th>
<th>Daily Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vegetative Biomass</td>
<td>Veg. Biomass</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>73.0</td>
<td>73.8</td>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>130.7</td>
<td>131.9</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>247.6</td>
<td>250.3</td>
<td>100.1</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>427.2</td>
<td>436.4</td>
<td>238.7</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>473.1</td>
<td>485.0</td>
<td>231.3</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>665.1</td>
<td>692.1</td>
<td>295.7</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>741.4</td>
<td>781.0</td>
<td>352.3</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>784.6</td>
<td>958.2</td>
<td>499.2</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>710.8</td>
<td>977.6</td>
<td>425.6</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>478.1</td>
<td>979.7</td>
<td>441.3</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>421.9</td>
<td>1191.0</td>
<td>286.1</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>383.5</td>
<td>1325.5</td>
<td>264.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mars</th>
<th>Days Past Flood</th>
<th>Aboveground Live</th>
<th>Total Aboveground</th>
<th>Daily Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vegetative Biomass</td>
<td>Veg. Biomass</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>92.8</td>
<td>95.7</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>134.3</td>
<td>137.7</td>
<td>19.1</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>236.5</td>
<td>240.2</td>
<td>423.9</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>379.0</td>
<td>390.9</td>
<td>542.4</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>554.6</td>
<td>566.0</td>
<td>629.6</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>571.9</td>
<td>609.1</td>
<td>929.9</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>636.1</td>
<td>792.1</td>
<td>818.0</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>557.4</td>
<td>723.0</td>
<td>793.9</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>486.3</td>
<td>831.3</td>
<td>477.8</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>408.8</td>
<td>916.0</td>
<td>594.7</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>358.9</td>
<td>983.7</td>
<td>372.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labelle</th>
<th>Days Past Flood</th>
<th>Aboveground Live</th>
<th>Total Aboveground</th>
<th>Daily Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vegetative Biomass</td>
<td>Veg. Biomass</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>132.2</td>
<td>133.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>232.6</td>
<td>238.5</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>329.4</td>
<td>337.2</td>
<td>149.3</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>447.2</td>
<td>458.3</td>
<td>246.8</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>633.5</td>
<td>682.9</td>
<td>332.8</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>604.6</td>
<td>787.5</td>
<td>355.5</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>593.7</td>
<td>912.7</td>
<td>439.6</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>473.2</td>
<td>1002.4</td>
<td>458.5</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>381.5</td>
<td>1026.9</td>
<td>384.4</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>302.9</td>
<td>979.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>