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ORNL-5786

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MARTIN MARIETTA

# A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture

Section 4

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## 4. SITE-SPECIFIC PARAMETERS

For a given location, as specified by a longitude-latitude coordinate ($X$, $Y$), TERRA simulates terrestrial transport by incorporating 21 site-specific agricultural and climatological parameters into its calculations. These parameters are available on a ½×½ degree longitude-latitude basis and are part of a data base, called SITE, which includes 36 agricultural, climatological, demographic, and other parameters. The remaining 15 parameters not used by the TERRA code are either used by or are available for use by the other codes of the CRRIS system. The agricultural parameters were derived from the report by Shor, Baes, and Sharp[7], which analyzes the 1974 Census of Agriculture.[209] Climatological parameters were interpolated from long-term averages recorded by United States weather stations as reported in several sources.[210-212] Demographic parameters describing the fraction of the population in various urbanization categories were available on a half-degree cell basis from the analyses of the 1970 U.S. Census by Haaland and Heath.[213,214] Estimates of population were taken from the 1980 U.S. Census.

The half-degree cell grid was preferred over the United States county resolution because of the variation in county area (Fig. 4.1). Bristol county, Rhode Island, the smallest county, is 64.5 km$^2$, and San Bernardino county, California, the largest, is 52,100 km$^2$, a range of over 800 fold. Half-degree cells provide a more uniform grid (Fig. 4.2). The areas of the cells vary from 2,030 km$^2$ at 49ºN latitude to 2,810 km$^2$ at 25ºN latitude—a variation of less than 30% over the conterminous United States. Half-degree cell areas are comparable to the areas of counties in northeast Texas (Fig. 4.1).

Each SITE cell is defined by an identification number, $i$, such that

$$i = 2[(X - 66.5) + 116(Y - 24.5)], \tag{27}$$

where

$X$ = the longitude (in degrees W) of the southeast corner of the cell and
$Y$ = the latitude (in degrees N) of the southeast corner of the cell.

Equation (27) is based on the reference point 66.5°W, 24.5°N and the fact that the conterminous United States lies between 66.5°W and 125°W. One hundred and sixteen half-degree cells define this span, horizontally.

Two methods were needed to convert county data to half-degree cell data because some data were stored per unit area and others were stored as a total count. The data stored as a total count was distributed according to the fraction of each county included in the individual cell (method A). The data stored per unit area was distributed according to the fraction of each cell included in the appropriate counties (method B). Both of these transformation fractions were determined for each SITE cell and each United States county using the IUCALC program which calculates polygon-polygon intersections, unions, and relative differences.[215] Table 4.1 shows the derivation of the number of cattle and calves, $n_{cc}$, and productivity of protected produce, $Y_p$, for SITE cell #3284, which has coordinates at the southeast corner of 84.5°W, 38.5°N. Three counties in Indiana and nine counties in Kentucky overlap this cell.

Method A is used for all parameters representing discrete entities, e.g., head of livestock, numbers of people, kilograms of produce. The assumption in effect is that number distribution is uniform throughout the county. The proportion of the county total within the cell is proportional to the area of the county within the cell. Method B is used for all parameters representing densities and representative averages, e.g., productivities and climatic variables. The effective assumption here is that the contribution from the county to the cell is proportional to the fraction of the cell which coincides with the county.

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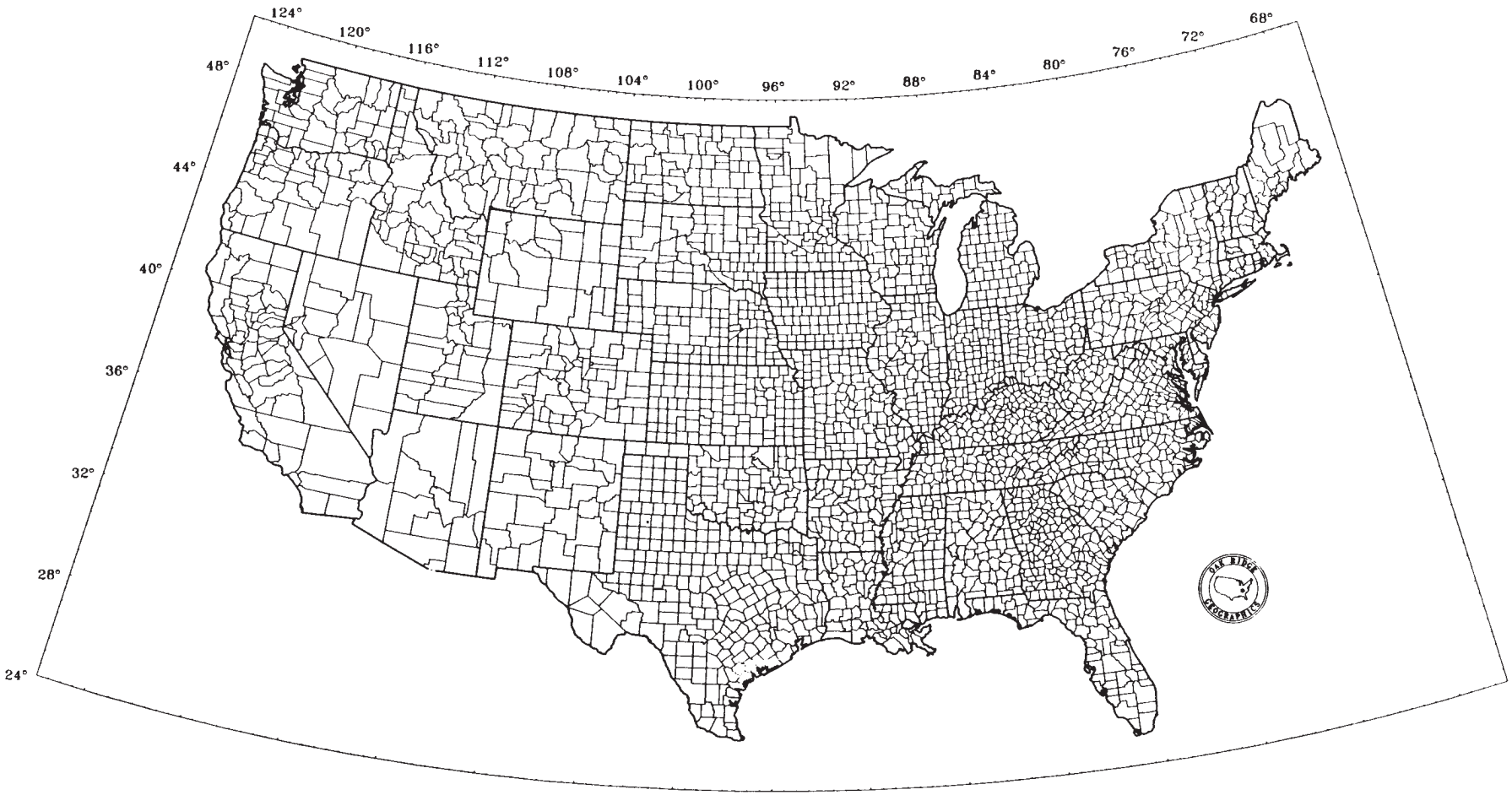


Figure 4.1. Map of the conterminous United States showing county delineations.

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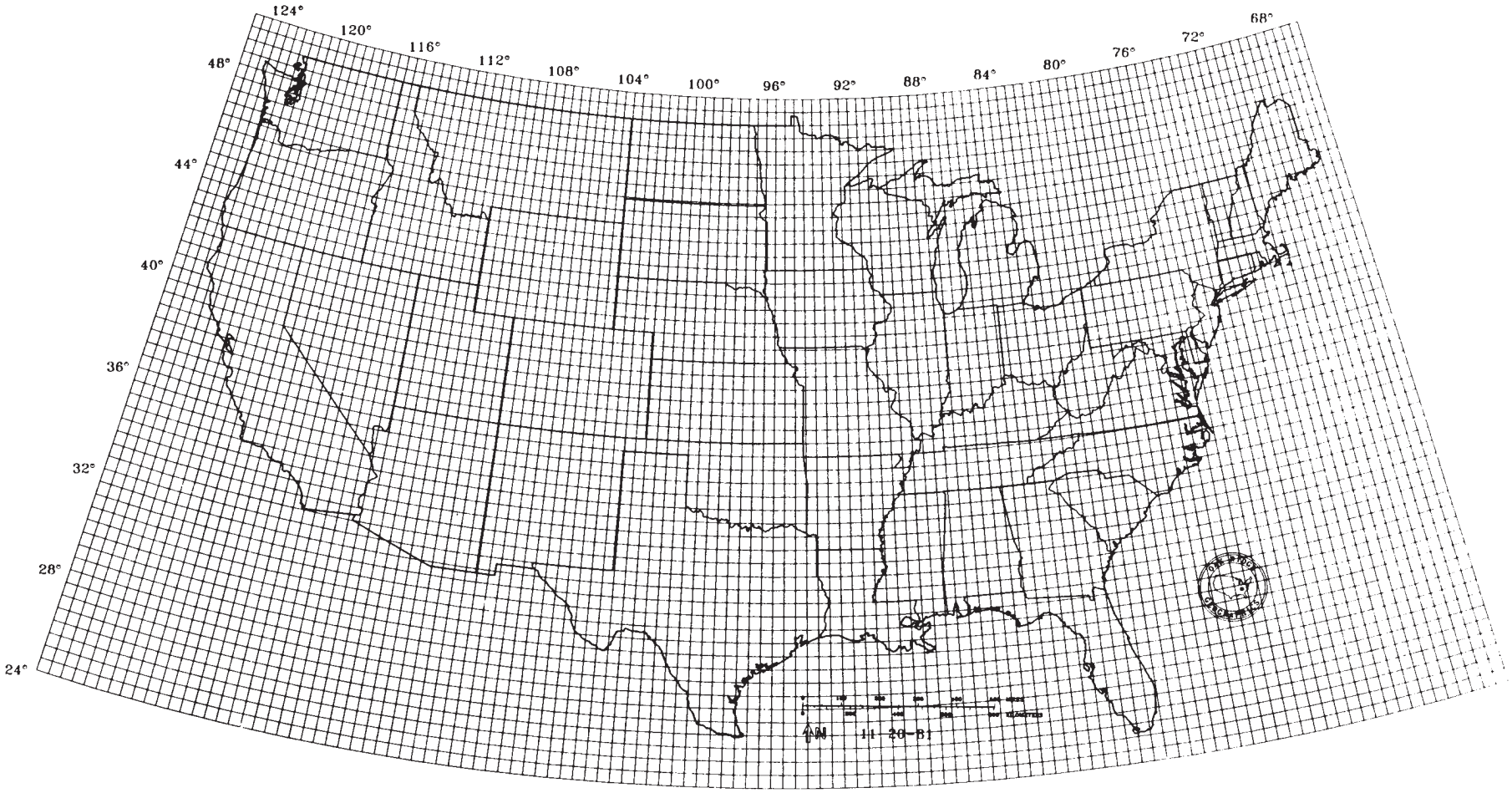


Figure 4.1. Map of the conterminous United States with half degree longitude-latitude grid indicated.

**Table 4.1. Example derivation of agricultural parameters for SITE cell #3284 from county-averaged parameters**

| County, state[a] | — Transfer parameter[b] — Method A | Method B | $n_{cc}^{c}$ (head) | $Y_{pp}^{d}$ (kg/m$^2$) |
|---|---|---|---|---|
| Dearborn, In | $3.60\times10^{-3}$ | $1.25\times10^{-3}$ | 17288 | 1.52 |
| Ohio, In | $5.59\times10^{-1}$ | $5.51\times10^{-2}$ | 7111 | 0.060 |
| Switzerland, In | $3.74\times10^{-1}$ | $9.38\times10^{-2}$ | 12863 | 0.060 |
| Boone, Ky | $6.18\times10^{-1}$ | $1.75\times10^{-1}$ | 20926 | 1.42 |
| Carroll, Ky | $8.45\times10^{-2}$ | $1.25\times10^{-2}$ | 11370 | 0.040 |
| Gallatin, Ky | $9.71\times10^{-1}$ | $1.10\times10^{-1}$ | 7512 | 2.12 |
| Grant, Ky | $9.31\times10^{-1}$ | $2.63\times10^{-1}$ | 22148 | 0.61 |
| Harrison, Ky | $9.00\times10^{-4}$ | $3.14\times10^{-4}$ | 44345 | 1.22 |
| Henry, Ky | $2.60\times10^{-3}$ | $8.52\times10^{-4}$ | 36319 | 0.78 |
| Kenton, Ky | $4.74\times10^{-1}$ | $8.88\times10^{-2}$ | 10633 | 1.18 |
| Owen, Ky | $4.91\times10^{-1}$ | $1.96\times10^{-1}$ | 26555 | 0.75 |
| Pendleton, Ky | $1.32\times10^{-2}$ | $4.18\times10^{-3}$ | 24125 | 0.82 |
| Total or average | | | 69190 | 0.99 |

[a]All counties which share area with SITE cell #3284 which has coordinates of southeast corner of 84.5°W, 38.5°N.

[b]For method A parameter is fraction of each county within the cell. For method B parameter is fraction of cell within each county.

[c]Number of cattle and calves.

[d]Yield of protected produce.

Climatological parameters were determined on a half degree cell basis by selecting the three United States weather stations nearest the centroid of the cell. The three parameter values for the weather stations were weighted according to distance from the weather station to the cell centroid such that

$$p_c = w_1 p_1 + w_2 p_2 + w_3 p_3 \,, \tag{28}$$

where

$p_c$ = the parameter value for the half degree cell,

$w_1$, $w_2$, $w_3$ = the weighting factors for the first, second, and third nearest weather stations, respectively, and

$p_1$, $p_2$, $p_3$ = the parameter values for the first, second, and third nearest weather stations, respectively.

The weighting factors were defined such that

$$w_1 + w_2 + w_3 = 1 \text{ and} \tag{29}$$

$$w = \frac{1}{d_l} \,, \tag{30}$$

where

$d_l$ = the linear distance between the weather station and the centroid of the cell.

The linear distance between weather stations and the centroid of the cell was determined by

$$\frac{kilometers}{1.0^\circ\, longitude} = A\cos Y + B + CY + DY^2 \text{ and} \tag{31}$$

$$\frac{kilometers}{1.0^\circ\, latitude} = \frac{Eq.(31)}{\cos Y} + E + FY + GY^2 \ . \tag{32}$$

where

$A$ = $1.113\times10^{2}$,
$B$ = $-9.855\times10^{-2}$,
$C$ = $7.789\times10^{-3}$,
$D$ = $-5.894\times10^{-5}$,
$E$ = $-8.570\times10^{-1}$,
$F$ = $7.927\times10^{-1}$, and
$G$ = $5.888\times10^{-5}$.

Table 4.2 shows example derivations of cell-averaged values of frost-free days from values from the three nearest United States weather stations.

### 4.1 Agricultural Parameters

The SITE data base contains 21 parameters describing location-specific agricultural practice, 14 of which are used by TERRA in simulating terrestrial transport of radionuclides. In addition, the climatic parameter, number of frost-free days, is used to estimate the number of harvests of hay and grazings of pasture by cattle. These parameters are described in detail in the report by Shor, Baes, and Sharp[7]. It is beyond the scope of this report to detail their derivation, but a brief description of their use in TERRA follows.

As discussed in Sect. 3., atmospheric deposition on edible portions of food and feed crops is inversely proportional to standing crop biomass. The best estimate of standing crop biomass at harvest is given by the productivity, defined as

$$Y_i = \frac{P_{hi}}{A_{hi}} \ , \tag{33}$$

where

$Y_i$ = the productivity (yield) of crop $i$ (kg/m$^2$),
$P_{hi}$ = the harvest yield (production) of crop $i$ (kg) per harvest, and
$A_{hi}$ = the area planted to crop $i$ which is harvested or harvest area (m$^2$).

For leafy vegetables, exposed and protected produce, grains, and silage, harvest yields and areas were obtained directly from the 1974 Census of Agriculture. However, for hay and pasture only, annual yields (summed over all harvests) and areas allocated for hay and pasture (not necessarily

**Table 4.2. Derivation of number of frost-free days for half-degree cells from values for the three nearest weather stations to the centroid of the cell[a]**

| Cell# | Longitude[b] | Latitude[c] | Stations | Weighting factors[d] | | | Frost-free days |
|---|---|---|---|---|---|---|---|
| | | | | $w_1$ | $w_2$ | $w_3$ | |
| 3615 | 76.0 | 40.0 | B, A, C | 0.462 | 0.287 | 0.251 | 203 |
| 3616 | 75.5 | 40.0 | B, F, E | 0.858 | 0.074 | 0.067 | 201 |
| 3617 | 77.0 | 40.0 | B, F, E | 0.612 | 0.225 | 0.163 | 201 |
| 3618 | 77.5 | 40.0 | B, F, E | 0.436 | 0.342 | 0.222 | 200 |
| 3731 | 76.0 | 40.5 | A, B, D | 0.372 | 0.334 | 0.294 | 185 |
| 3732 | 76.5 | 40.5 | B, A, D | 0.489 | 0.262 | 0.249 | 189 |
| 3733 | 77.0 | 40.5 | B, F, D | 0.525 | 0.241 | 0.234 | 189 |
| 3847 | 76.0 | 41.0 | D, A, B | 0.508 | 0.279 | 0.213 | 181 |

[a]The following weather station values were used:
A = Allentown, Pa: 180 frost-free days
B = Harrisburg, Pa: 201 frost-free days
C = Philadelphia, Pa: 232 frost-free days
D = Scranton, Pa: 174 frost-free days
E = Baltimore, Md: 234 frost-free days
F = Frederick, Md: 176 frost-free days.
[b]Southeast corner of cell.
[c]First, second, and third nearest weather station, respectively.
[d]Given by Eqs. (30) and (31).

areas actually harvested) were given or derived from census information. Thus, for hay and pasture Shor, Baes, and Sharp[7] calculated "area1 yields" defined by

$$Y_i^a = \frac{P_{ai}}{A_i}, \tag{34}$$

where

$Y_i^a$ = the area1 yield of crop $i$ (kg/yr/m$^2$),
$P_{ai}$ = the annual yield of crop $i$ (kg/yr), and
$A_i$ = the inventory area for crop $i$ (m$^2$).

The sum of all harvest yields (production) and productivity estimates for leafy vegetables (Figs. 4.3 and 4.4), exposed produce (Figs. 4.5 and 4.6), protected produce (Figs. 4.7 and 4.8), grain for food (Figs. 4.9 and 4.10), grain for feed (Figs. 4.11 and 4.12), and silage (Figs. 4.13 and 4.14) are included in the SITE data base. Also included are the annual yield (production) of hay (Fig. 4.15) and area1 yield estimate for hay (Fig. 4.16). The area1 yield of pasture estimate is not included in the SITE data base, but is calculated in TERRA from information contained in SITE (as discussed below). The productivity estimates for hay and pasture are calculated by dividing area1 yields by the estimated numbers of hay harvests and successive pasture grazings by cattle, respectively.

Number of harvests per year for hay is initially estimated by

$$h_h = \frac{d_{ff}}{60\ days}, \tag{35}$$

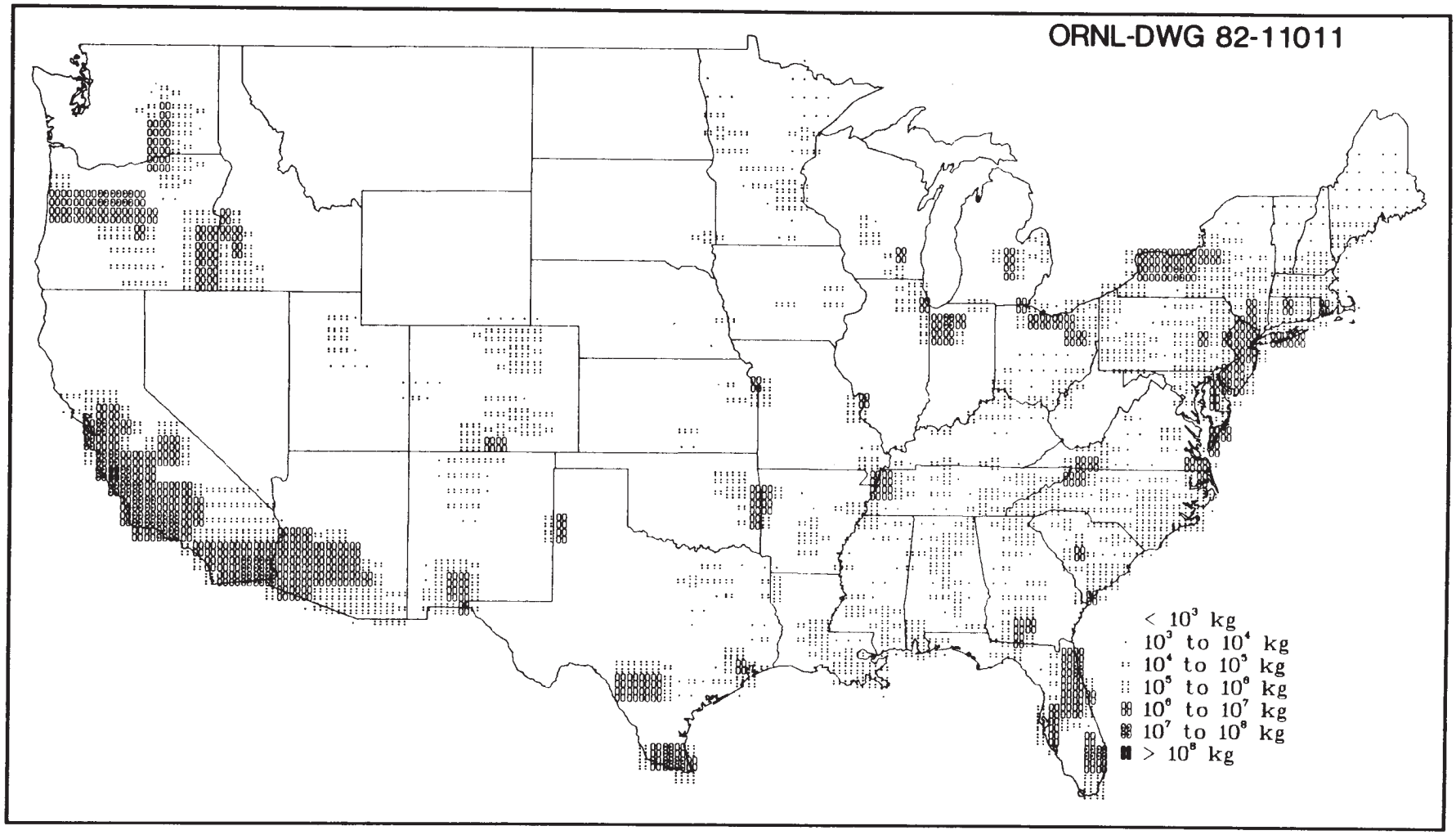


Figure 4.3. Geographic distribution of SITE parameter leafy vegetable production, $P_{lv}$

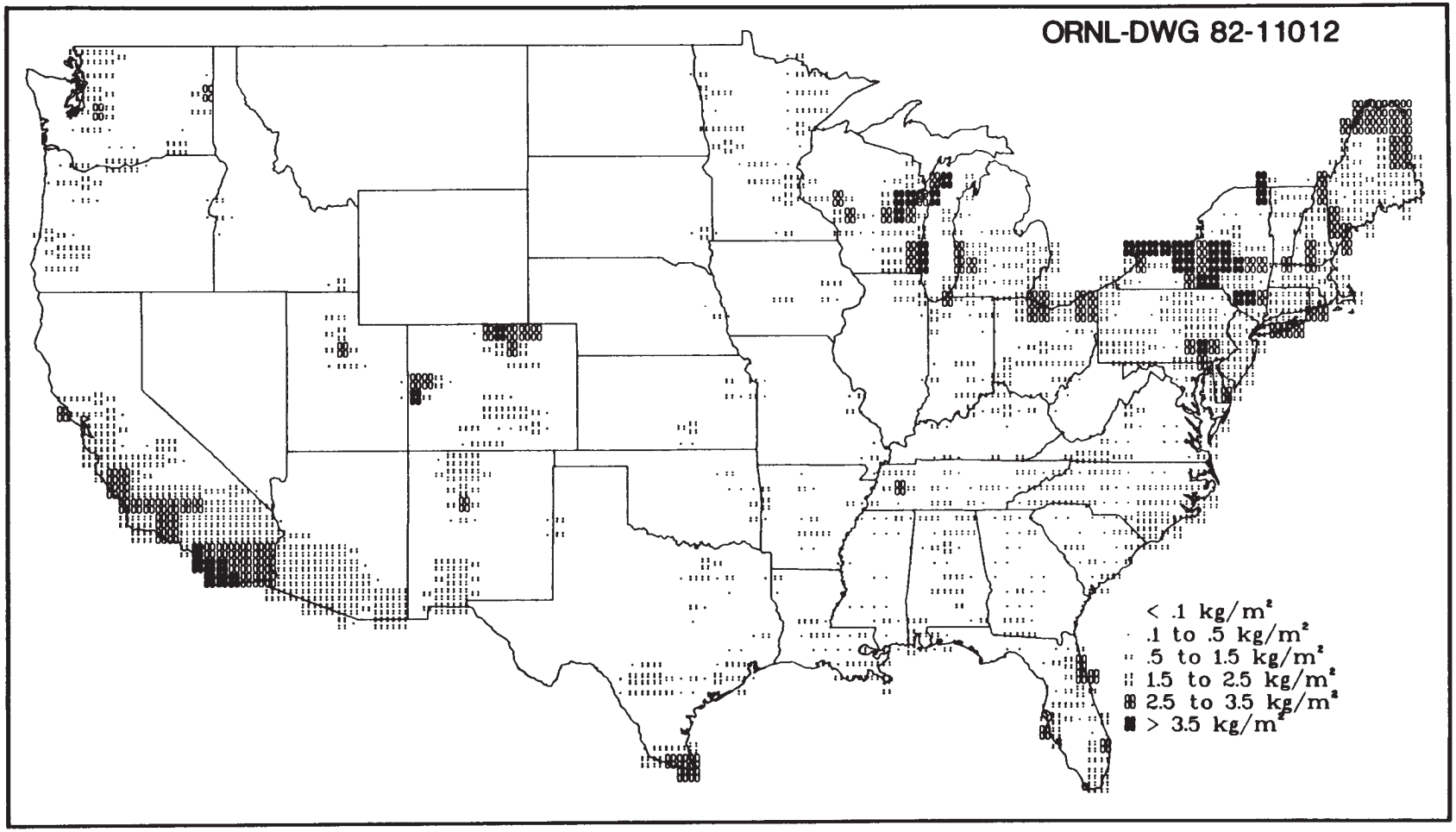


Figure 4.4. Geographic distribution of SITE parameter leafy vegetable productivity, $Y_{lv}$

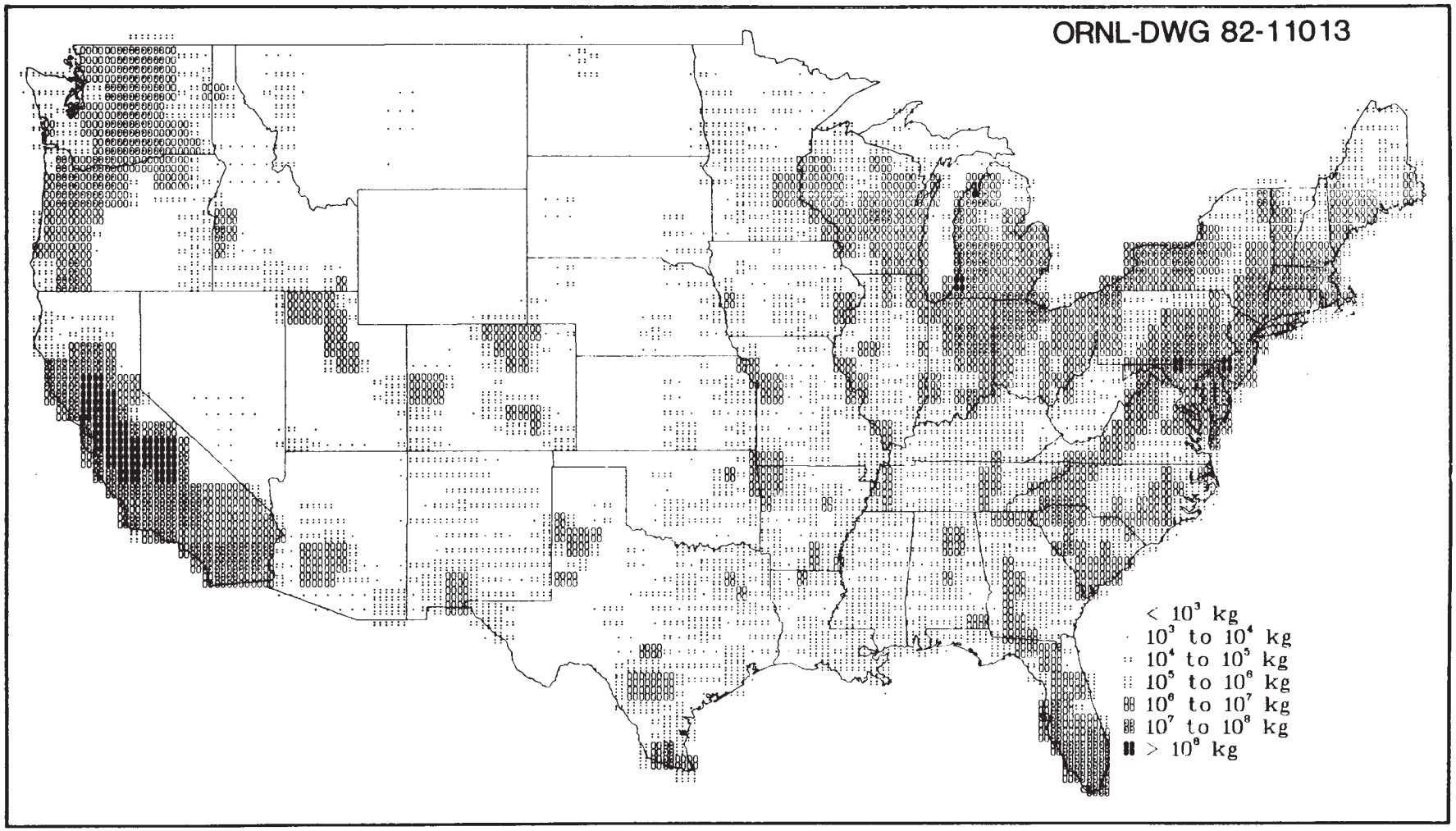


Figure 4.5. Geographic distribution of SITE parameter exposed produce production, $P_e$

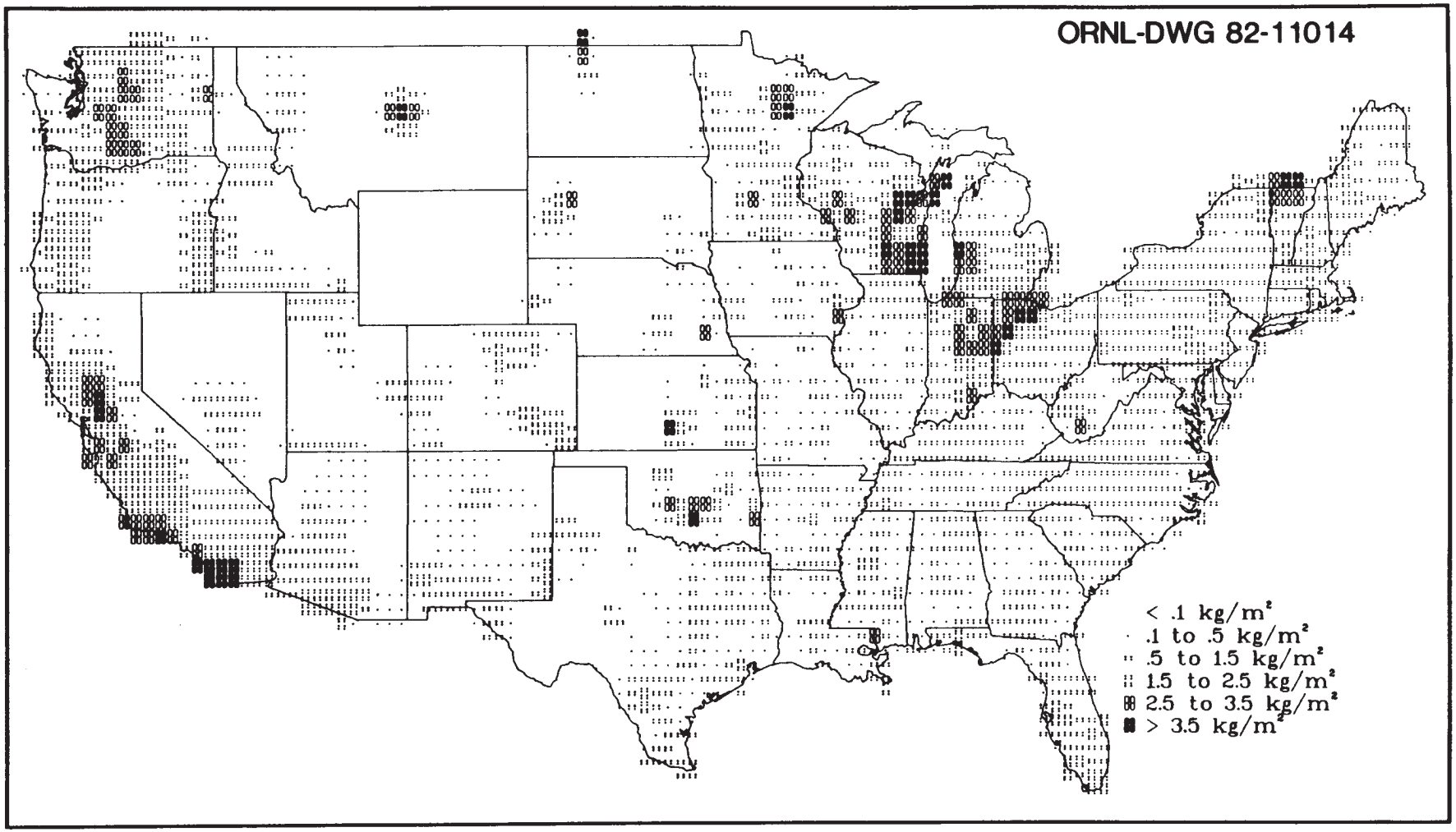


Figure 4.6. Geographic distribution of SITE parameter exposed produce productivity, $Y_e$

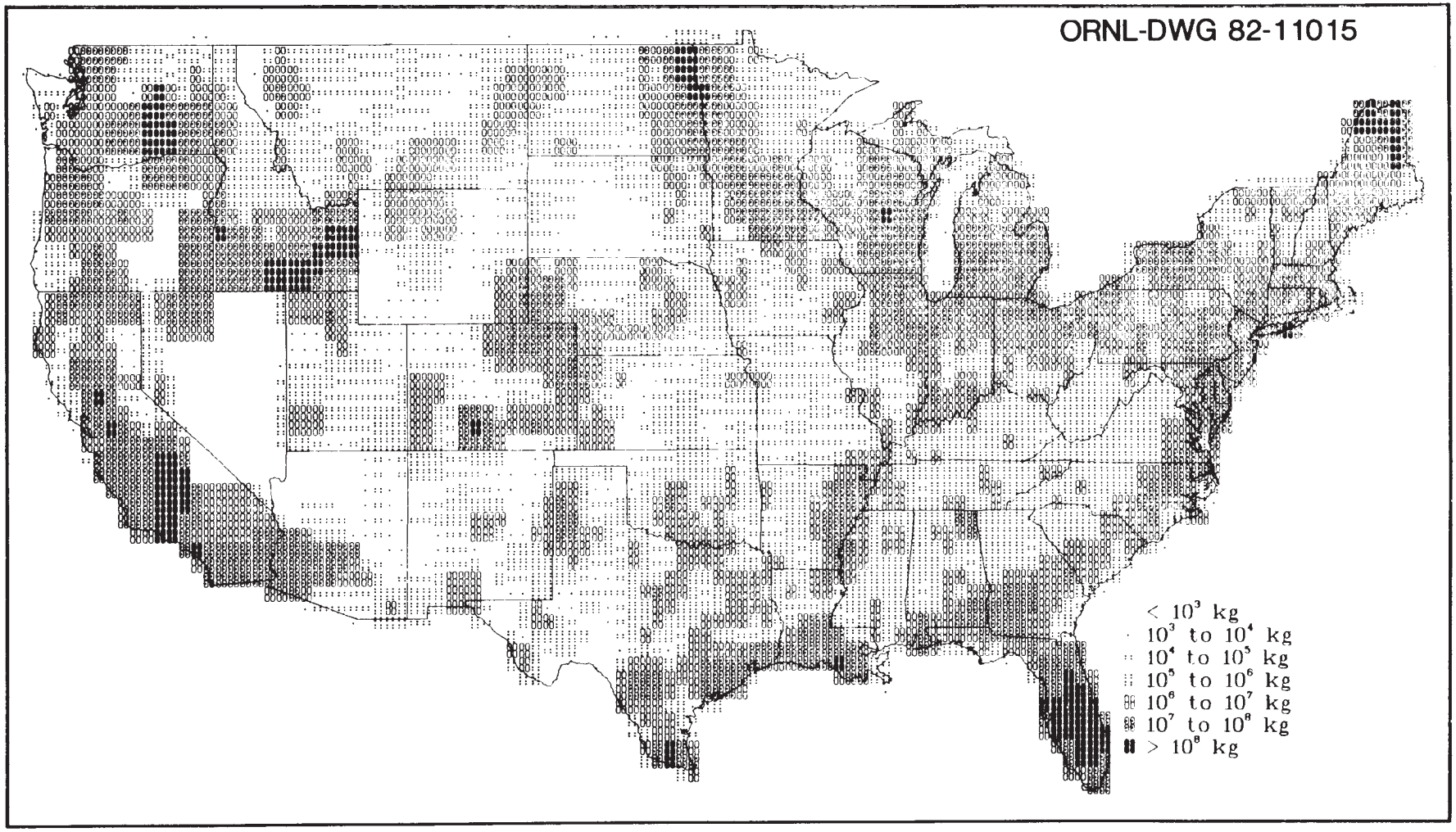


Figure 4.7. Geographic distribution of SITE parameter protected produce production, $P_{pp}$

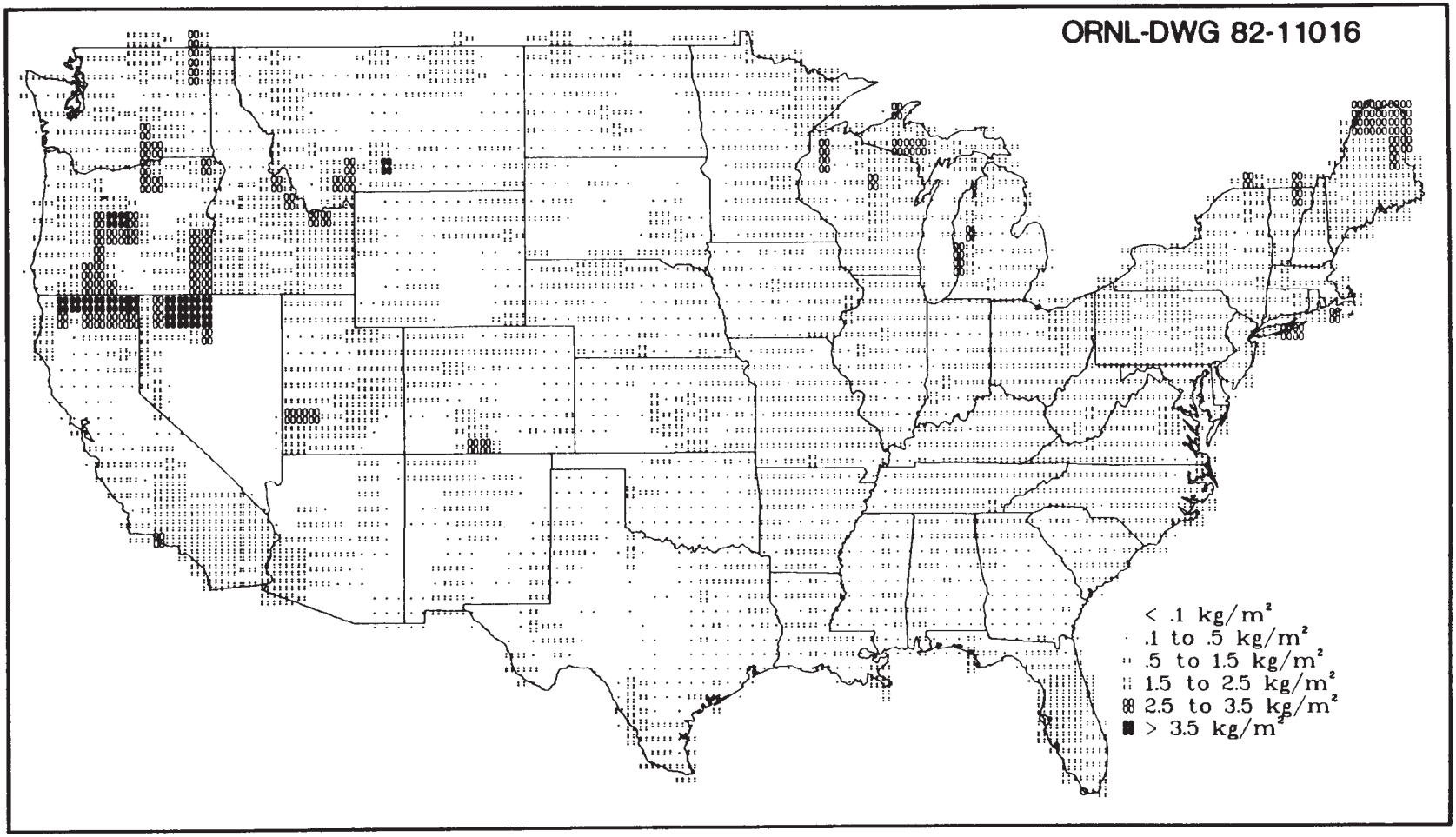


Figure 4.8. Geographic distribution of SITE parameter protected produce productivity, $Y_{pp}$

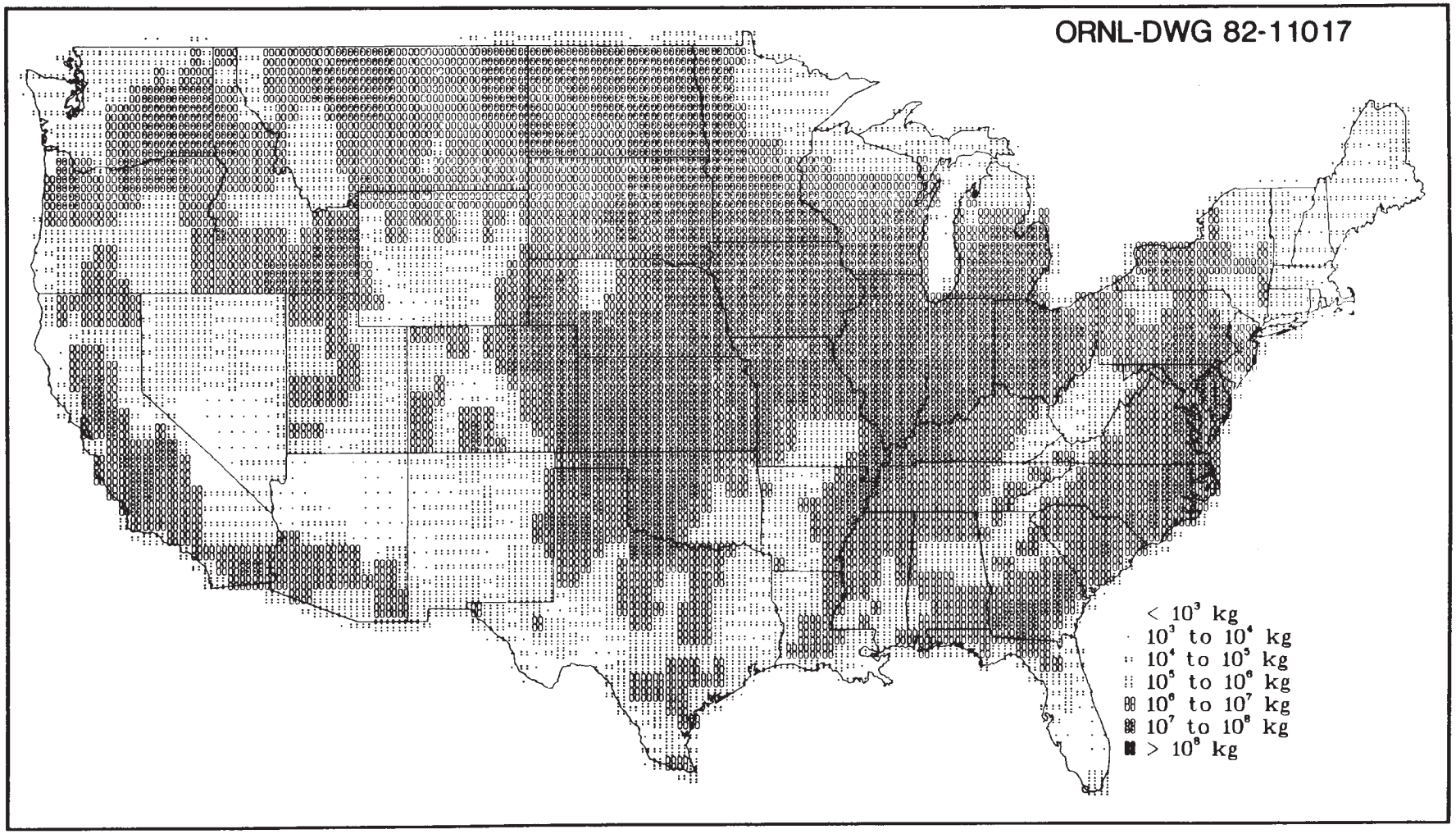


Figure 4.9. Geographic distribution of SITE parameter grain food production, $P_{g\,h}$

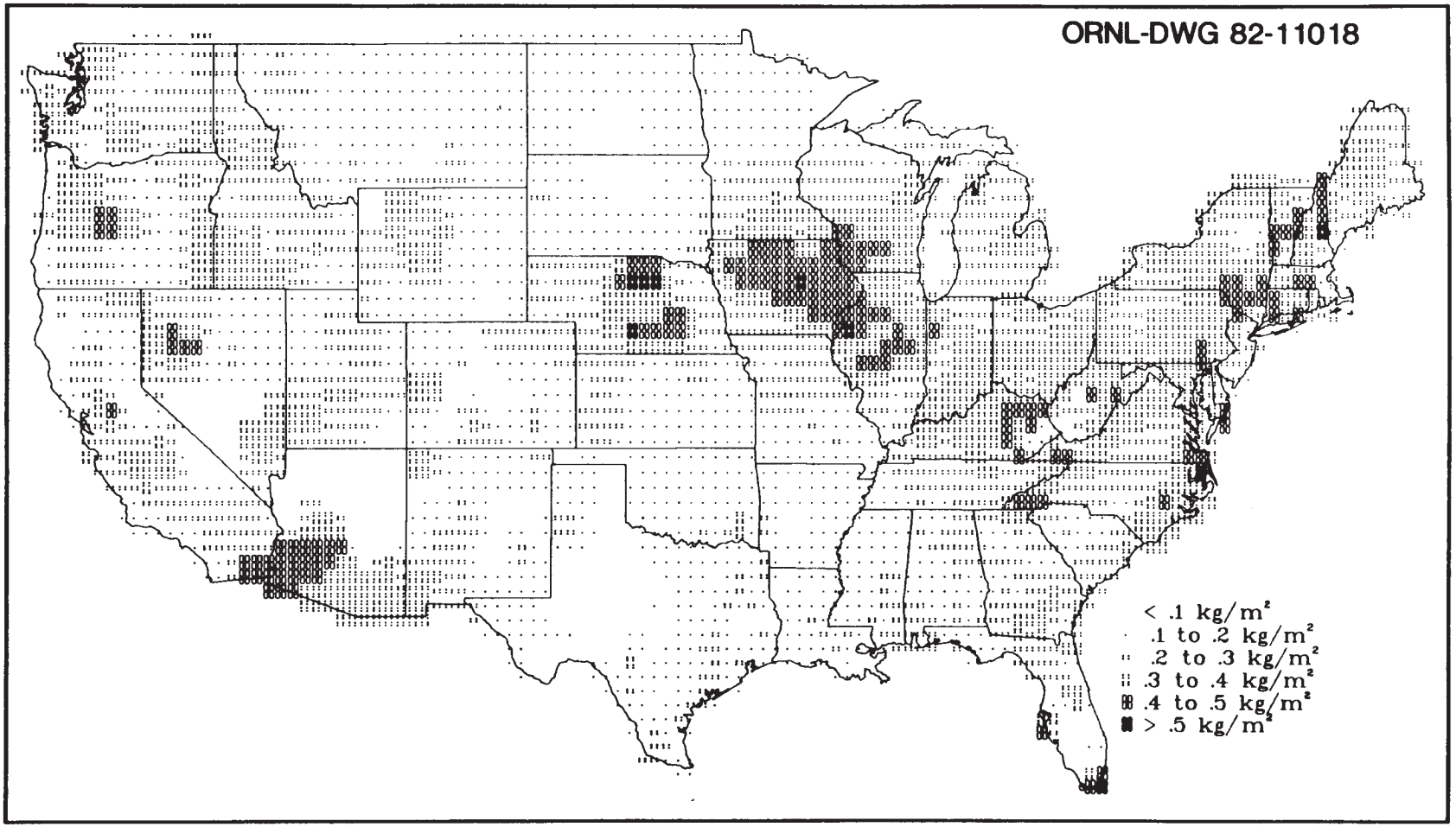


Figure 4.10. Geographic distribution of SITE parameter grain food productivity, $Y_{gh}$

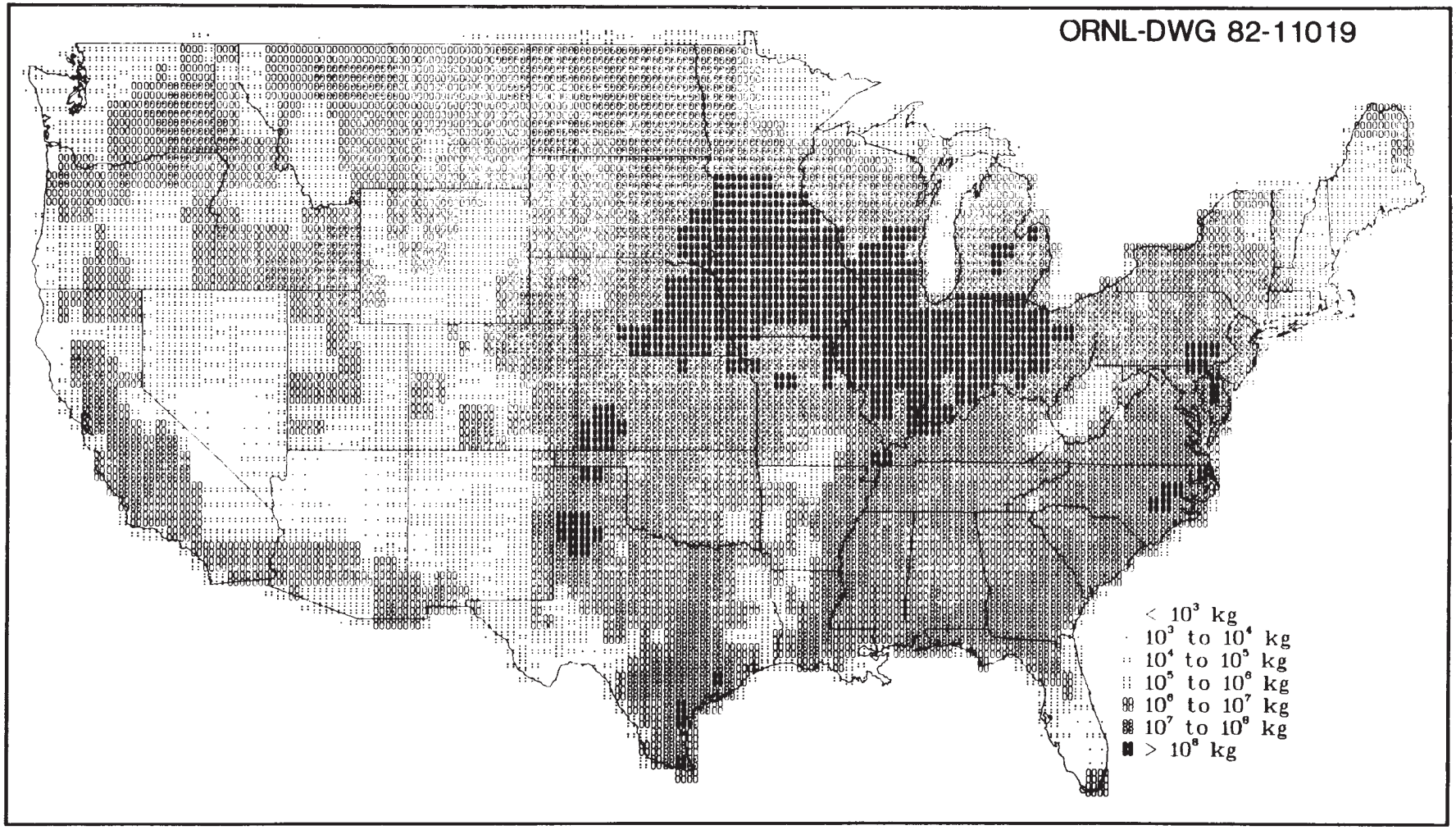


Figure 4.11. Geographic distribution of SITE parameter grain feed production, $P_{gf}$

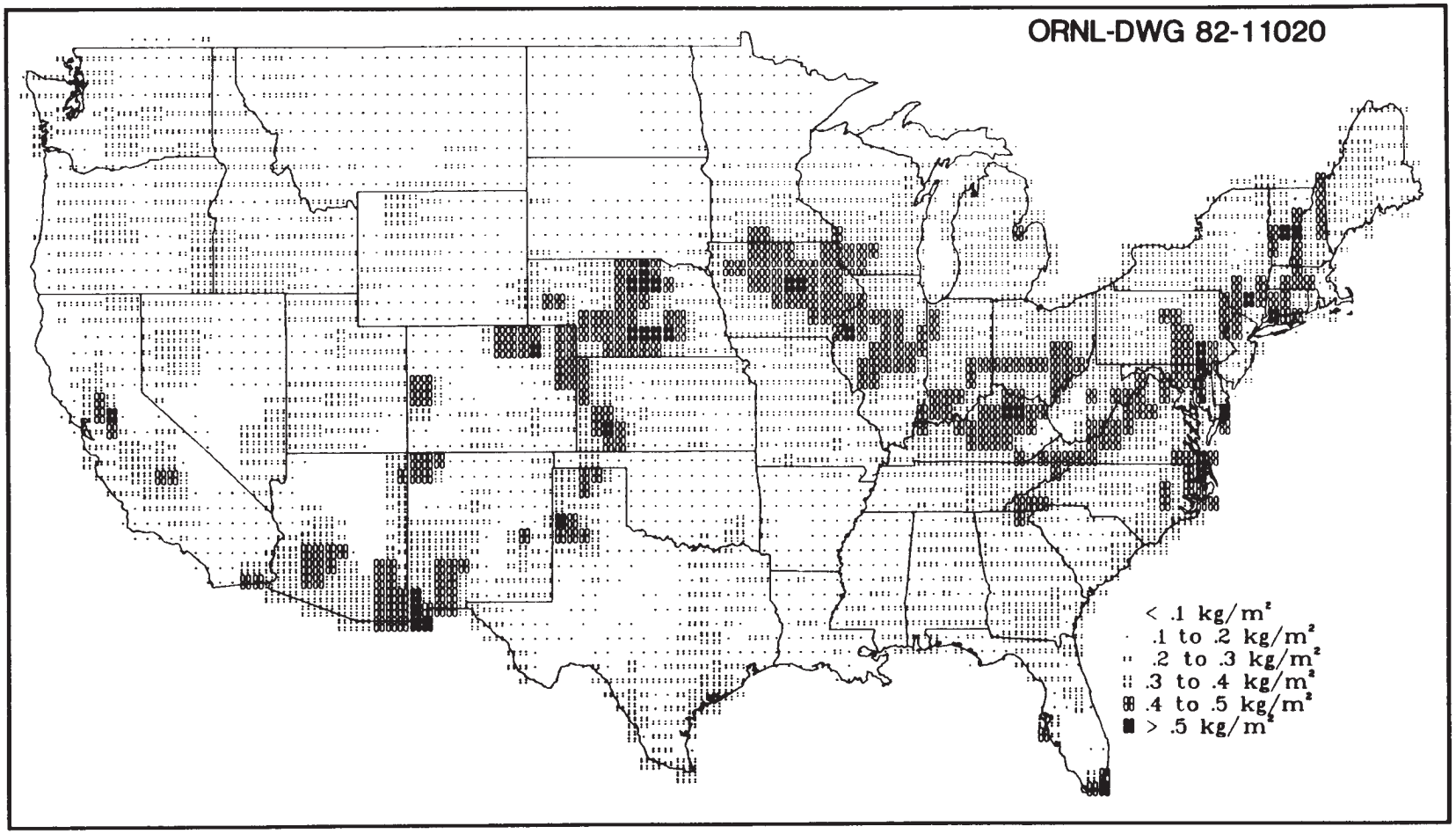


Figure 4.12. Geographic distribution of SITE parameter grain feed productivity, $Y_{gf}$

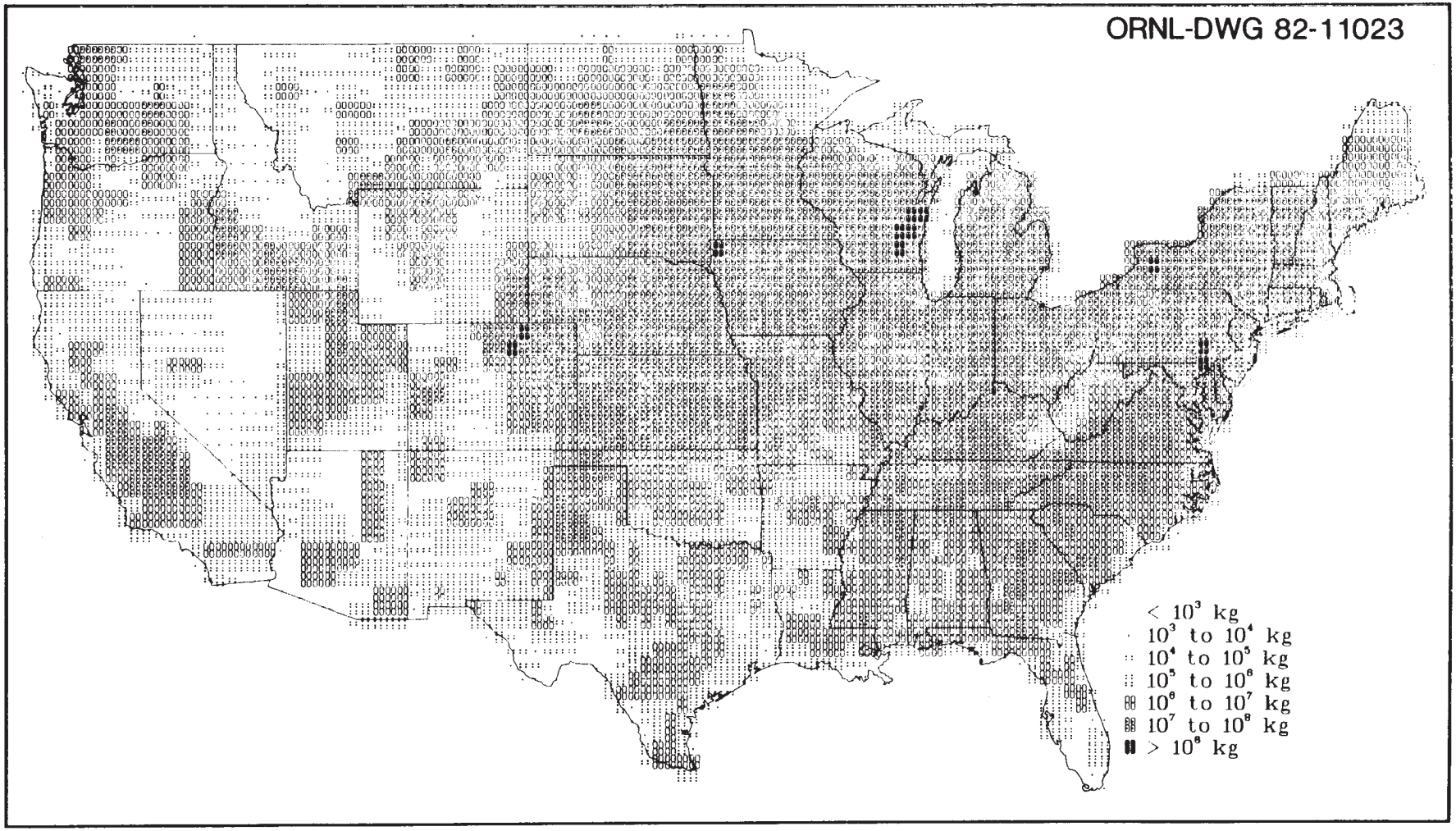


Figure 4.13. Geographic distribution of SITE parameter silage feed production, $P_s$

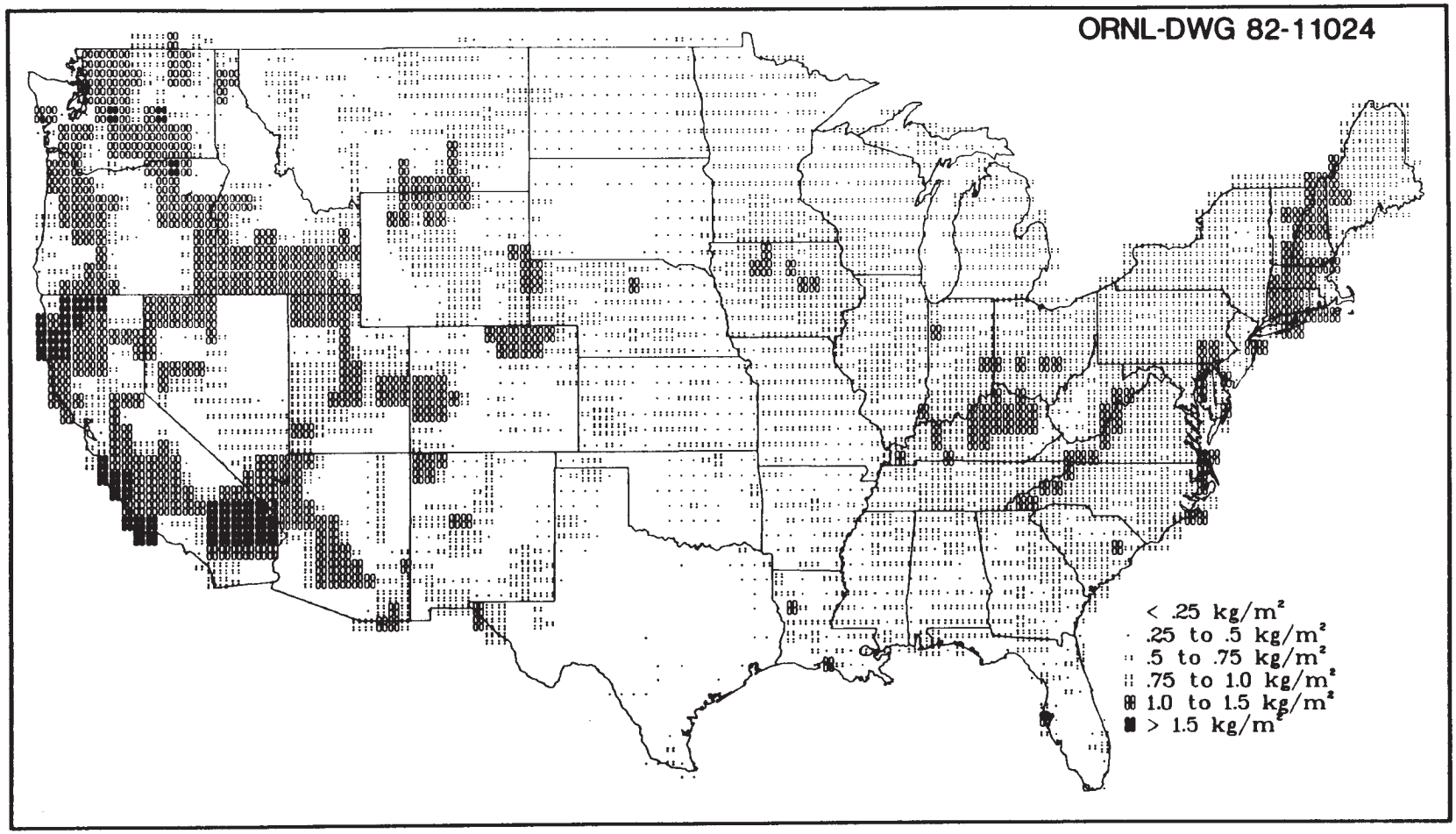


Figure 4.14. Geographic distribution of SITE parameter silage feed productivity, $Y_s$

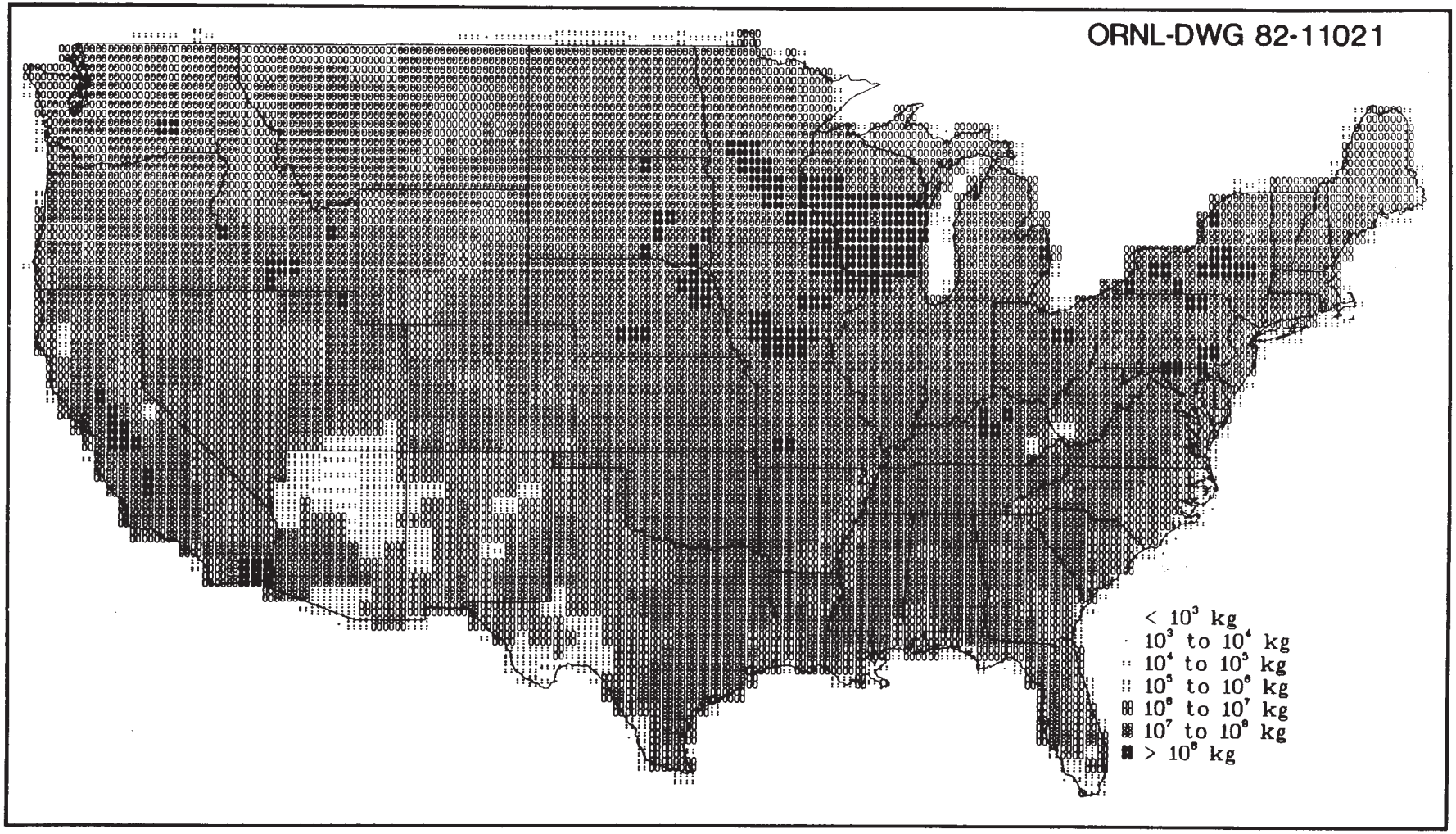


Figure 4.15. Geographic distribution of SITE parameter hay feed production, $P_h$

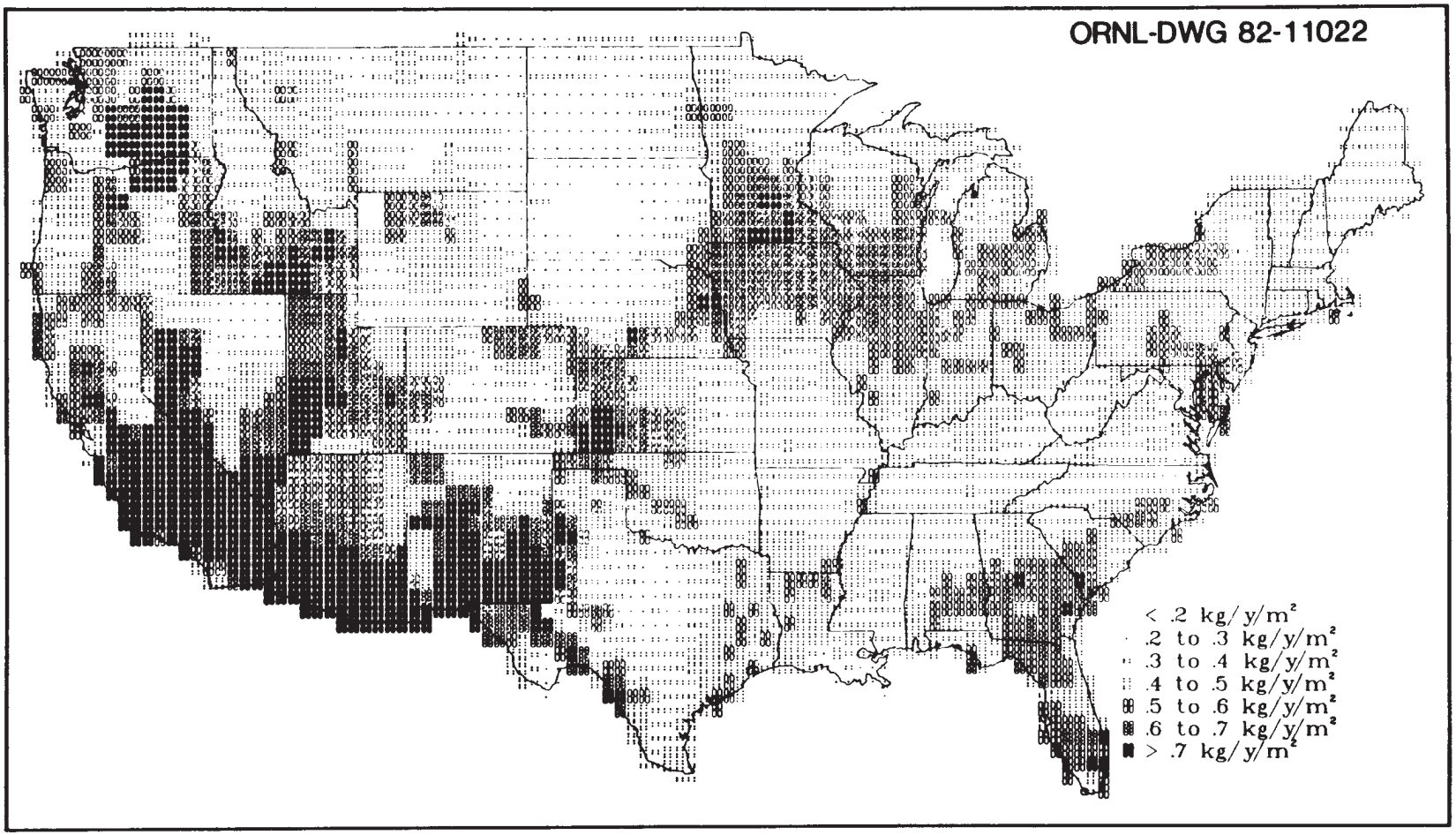


Figure 4.16. Geographic distribution of SITE parameter hay feed areal yield, $Y_h^a$

where

$h_h$ = the number of hay harvests ($yr^{-1}$),
$d_{ff}$ = the number of frost-free days (day/yr), and
60 days = the average time between successive hay harvests.[7]

The initial estimate of $h_h$ is rounded off to the nearest integer and hay productivity, $Y_h$, is calculated according to

$$Y_h = \frac{P_h}{h_h} . \tag{36}$$

If $Y_h < 0.10$ kg/m$^2$, then the initial estimate of $h_h$ is reduced to the largest integer for which $Y_h > 0.10$ kg/m$^2$. The value of 0.10 kg/m$^2$ is considered the minimum productivity at which hay harvesting is economically feasible.[7] The same general procedure is followed for calculation of pasture grass productivity, $Y_{pg}$, except that the initial estimate of successive grazings (harvests) by cattle, $g_{pg}$, is given by

$$g_{pg} = \frac{d_{ff}}{30\ days} , \tag{37}$$

where

30 days = the average time between successive grazings by cattle.[6]

and the minimum productivity is 0.005 kg/m$^2$.[7] The SITE data base includes estimated number of frost-free days in a year (Fig. 4.17).

In TERRA the area1 yield of pasture grass, from which pasture grass productivity is calculated, is estimated from the cattle and calf inventory, $n_{cc}$ (Fig. 4.18), the inventory of milk cows, $n_m$ (Fig. 4.19), the annual sales of cattle on grain, $s_g$ (Fig. 4.20), and the inventory of sheep, $n_s$ (Fig. 4.21), in the manner described in Section 5.1 of the report by Shor, Baes, and Sharp.[7] Briefly, annual consumption of pasture grass is defined by a mass balance of livestock forage requirement or need and harvested supply. The difference between need and supply is assumed to be pasture consumption. The harvested supply is defined as 75% of hay and silage production, and need is defined according to the numbers and types of forage consuming livestock. The following equations are used to calculate pasture grass area1 yield $Y_{pg}^a$ in TERRA:

$$Y_{pg}^a = \frac{C_p}{A_p} , \tag{38}$$

where

$C_p$ = the annual consumption of pasture in a half-degree cell by livestock (kg/yr) and
$A_p$ = the area of pasture (Fig. 4.22) in the cell (m$^2$).

Pasture consumption is calculated according to

$$C_p = R_f - 0.75 P_{hf} \text{ , and} \tag{39}$$

$$P_{hf} = P_s + P_h ,$$

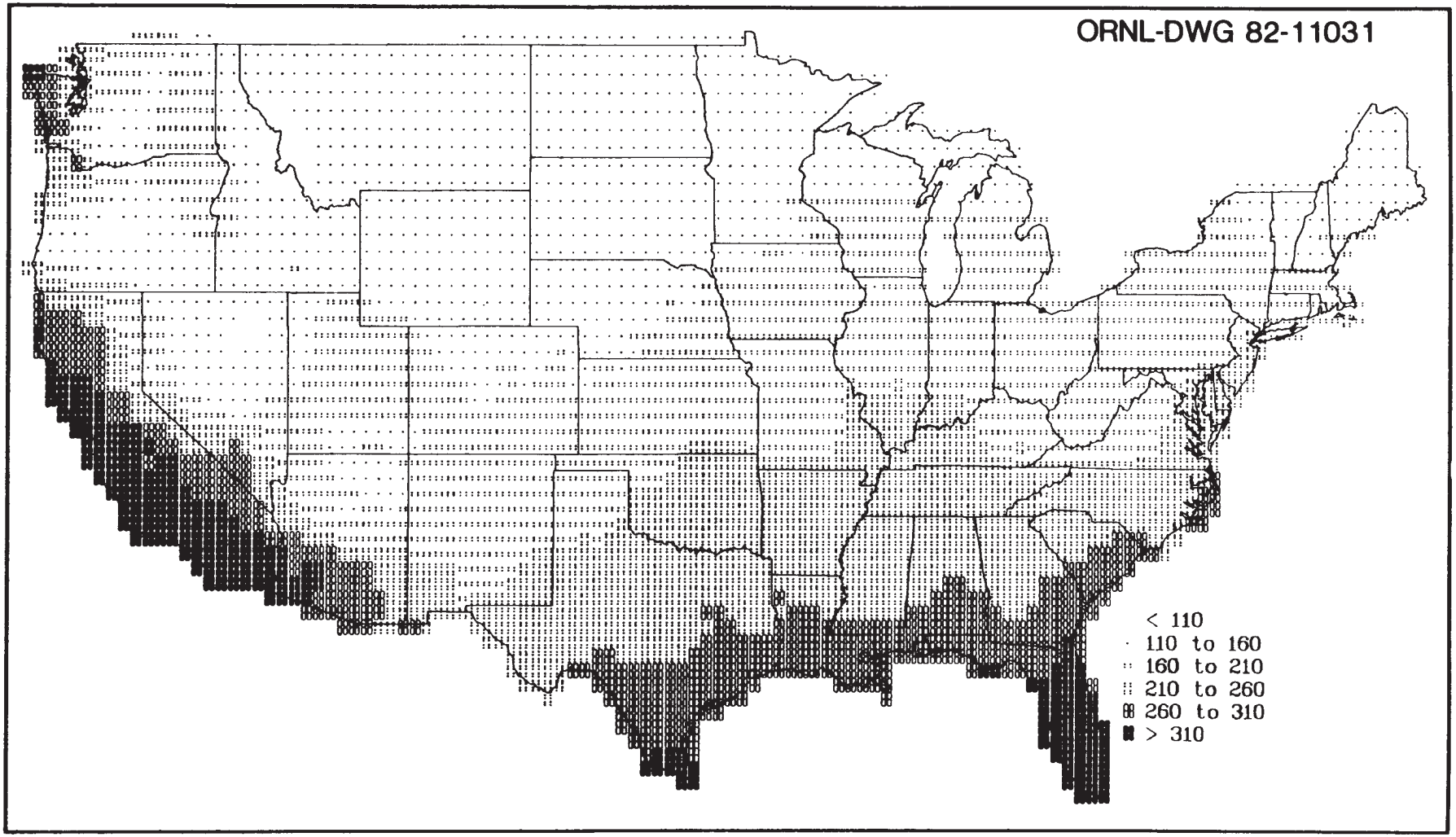


Figure 4.17. Geographic distribution of SITE parameter number of frost-free days, $d_{ff}$

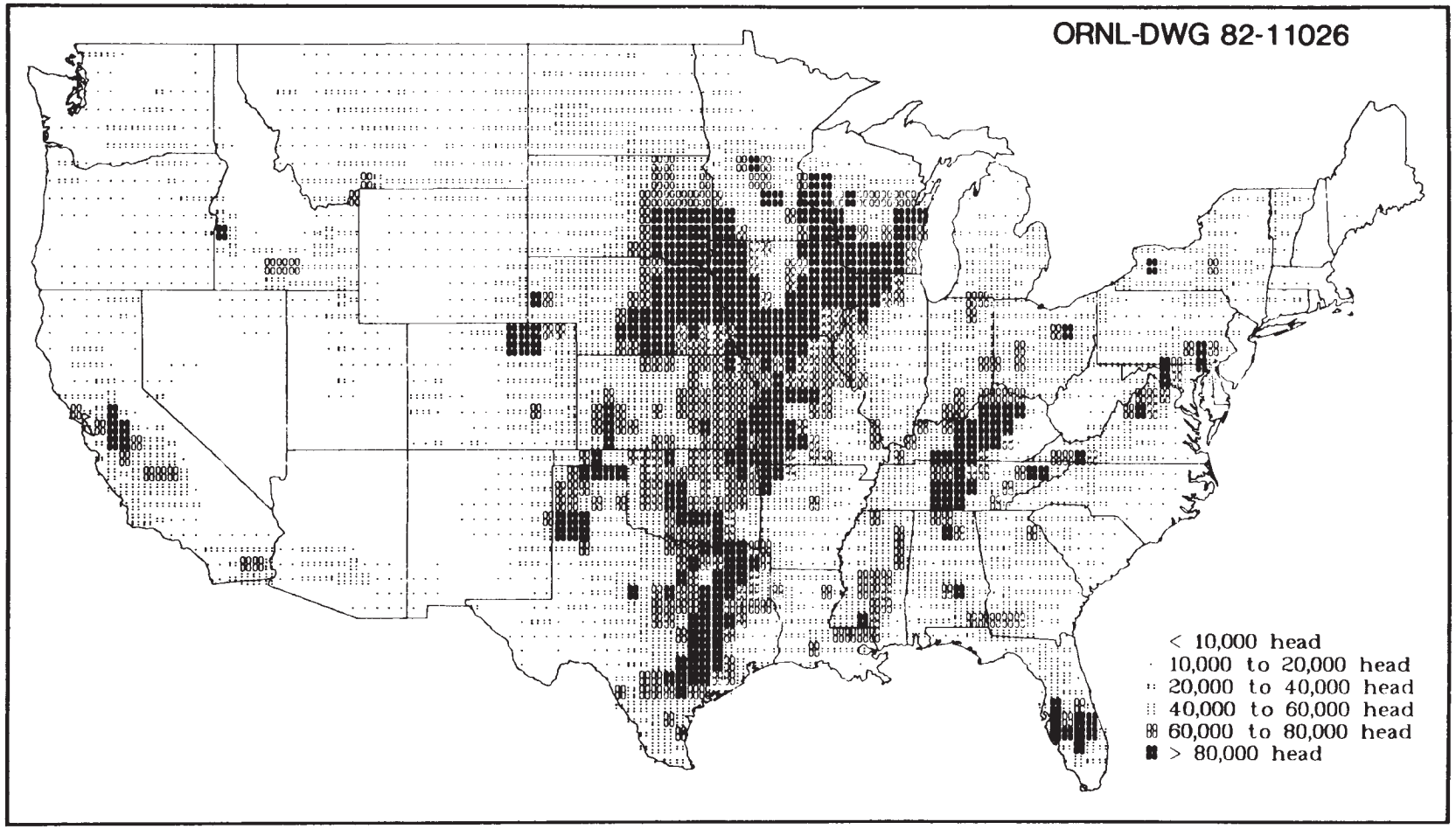


Figure 4.18. Geographic distribution of SITE parameter number cattle and calves inventory, $n_{cc}$

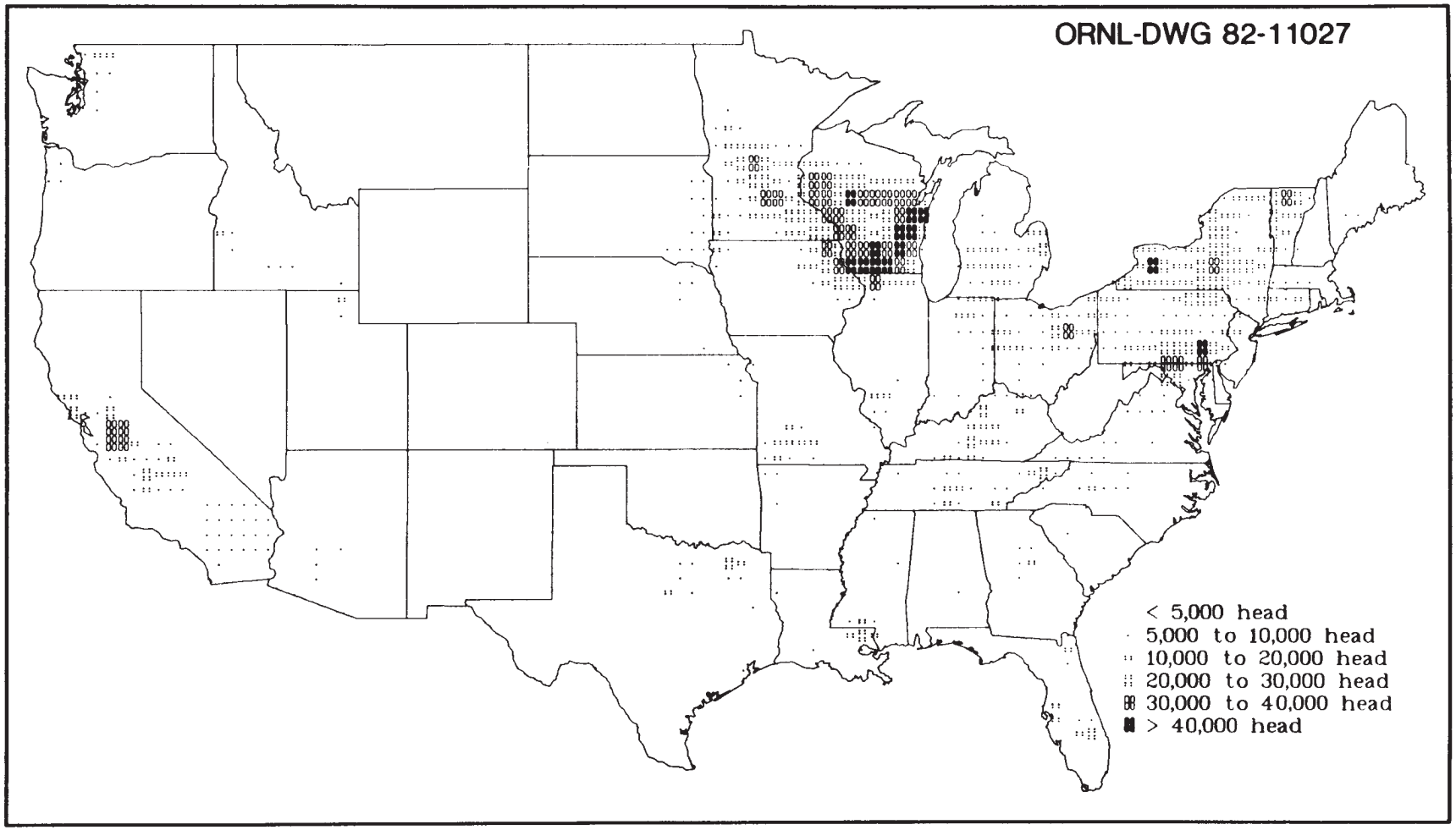


Figure 4.19. Geographic distribution of SITE parameter milk cow inventory, $n_m$

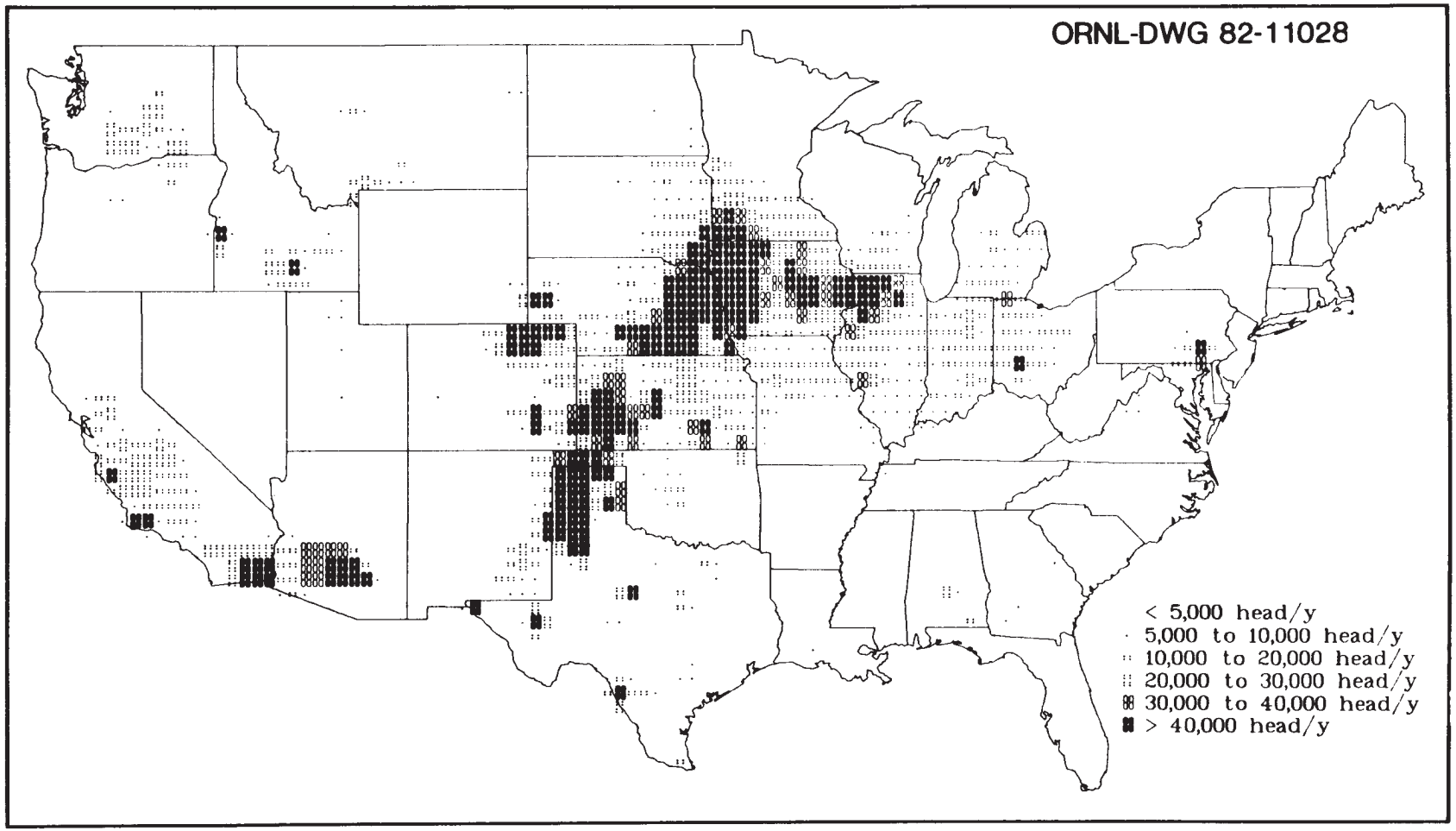


Figure 4.20. Geographic distribution of SITE parameter annual number of cattle on feed sold, $s_g$

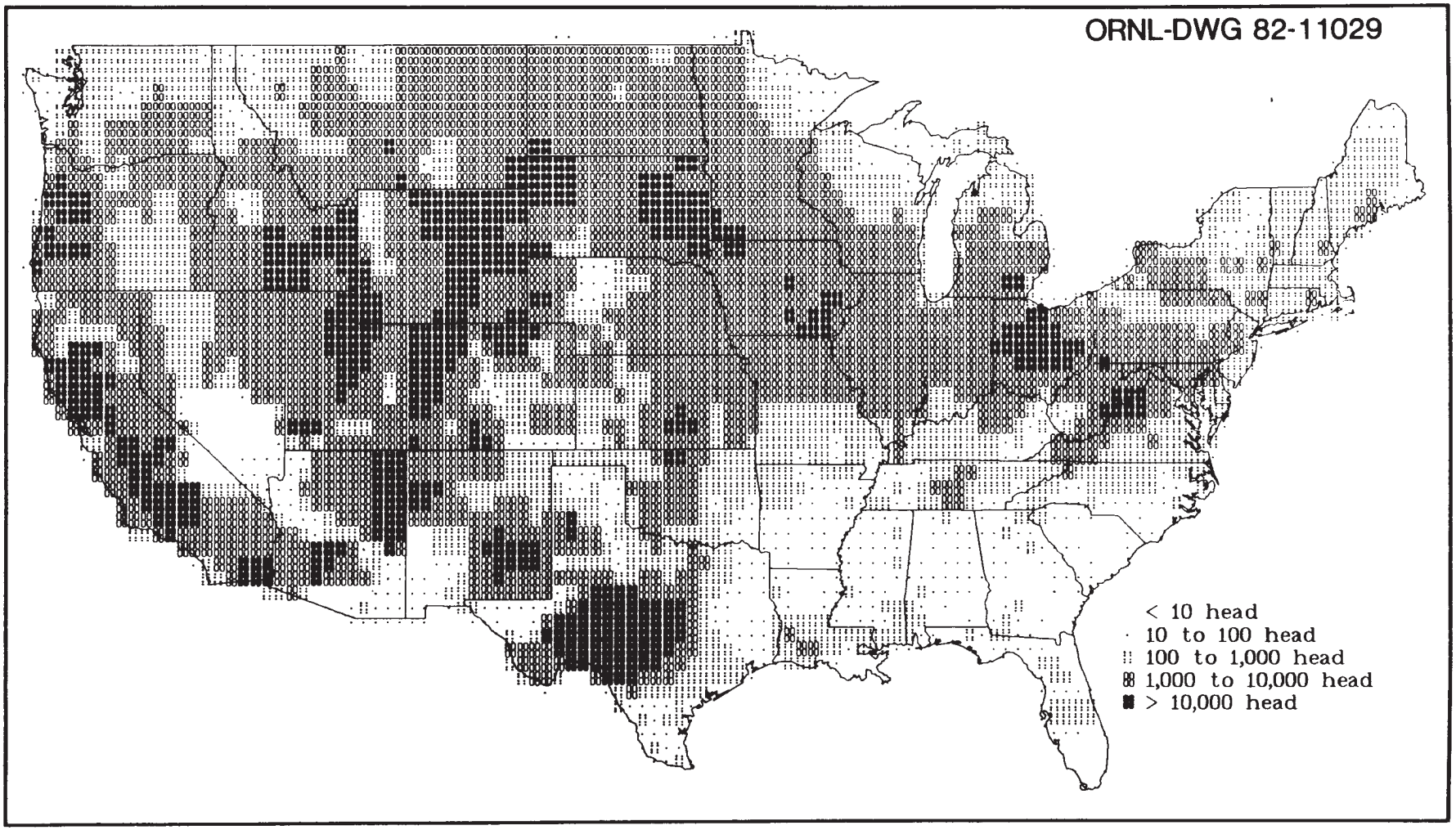


Figure 4.21. Geographic distribution of SITE parameter sheep inventory, $n_s$

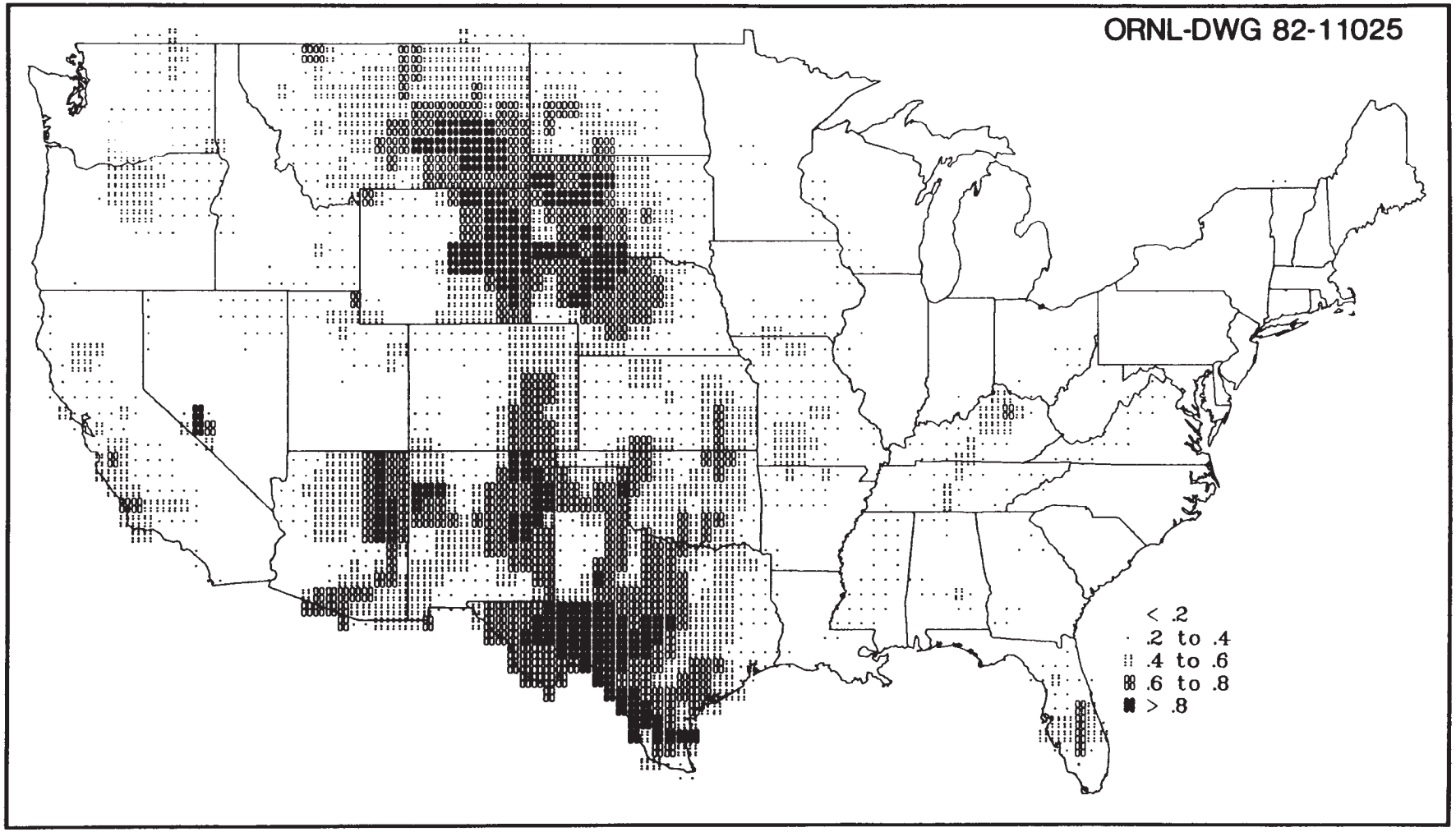


Figure 4.22. Geographic distribution of SITE parameter pasture area, $A_p$, shown as a fraction of total cell area.

where

$R_f$ = the collective forage requirement by forage-consuming livestock in the cell (kg/yr),
$P_{hf}$ = annual production of harvested forage in the cell (kg/yr),
$P_s$ = the annual production of silage in the cell (kg/yr), and
$P_h$ = the annual production of hay in the cell (kg/yr).

The collective livestock forage requirement is given by

$$R_f = 4010 n_m + 970 n_g + 3030 n_a + 600 n_s \ , \tag{41}$$

where

$n_g$ = the inventory of cattle on grain (head) in the cell,
$n_a$ = the average annual inventory of "all other cattle" (neither milk cows or cattle on feed) in the cell (head), and

the coefficients are annual forage requirements for each livestock category (kg/head/yr).[7] Inventory numbers of milk cows, $n_m$, and sheep, $n_s$, are given in SITE, and $n_g$ and $n_a$ are calculated by

$$n_g = \frac{s_g}{\lambda_g} \text{, and} \tag{42}$$

$$n_a = n_{cc} - n_m - \frac{3}{2} n_g \ , \tag{43}$$

where

$\lambda_g$ = the turnover rate of cattle on feed grain (1/yr).

The number of cattle and calves in the cell, $n_{cc}$, is given in SITE. The turnover rate $\lambda_g$ is assumed to be 2.0/yr.[7]

In some states, notably Texas, Oklahoma, Nebraska, and Kansas, large numbers of cattle are imported and placed on feedlots for fattening. In these areas Eq. (43) may produce a negative value due to the high value of $n_g$. This possibility is tested for in the TERRA code, and when Eq. (43) is negative the value of $n_a$ is set equal to the SITE parameter beef cow inventory, $n_b$ (Fig. 4.23).

As shown in Eq. (39), all forage consumed by livestock in a cell is assumed to be produced locally within the cell in TERRA. This type of assumption is not applied to grain. That is, a grain requirement for all livestock in the cell is calculated according to

$$R_g = 2600 n_m + 1820 n_g + 150 n_a \ , \tag{44}$$

where

$R_g$ = the collective grain requirement of all grain-consuming livestock in the cell (kg/yr) and

the coefficients are the annual grain requirements for each livestock category (kg/head/yr).[7] Sheep are assumed to consume forage only. The grain requirement is compared to the SITE parameter, annual harvest yield or production of grain feed, $P_{gf}$ (kg), and the fraction of grain imported from outside of the cell, $f_{gi}$, is calculated according to

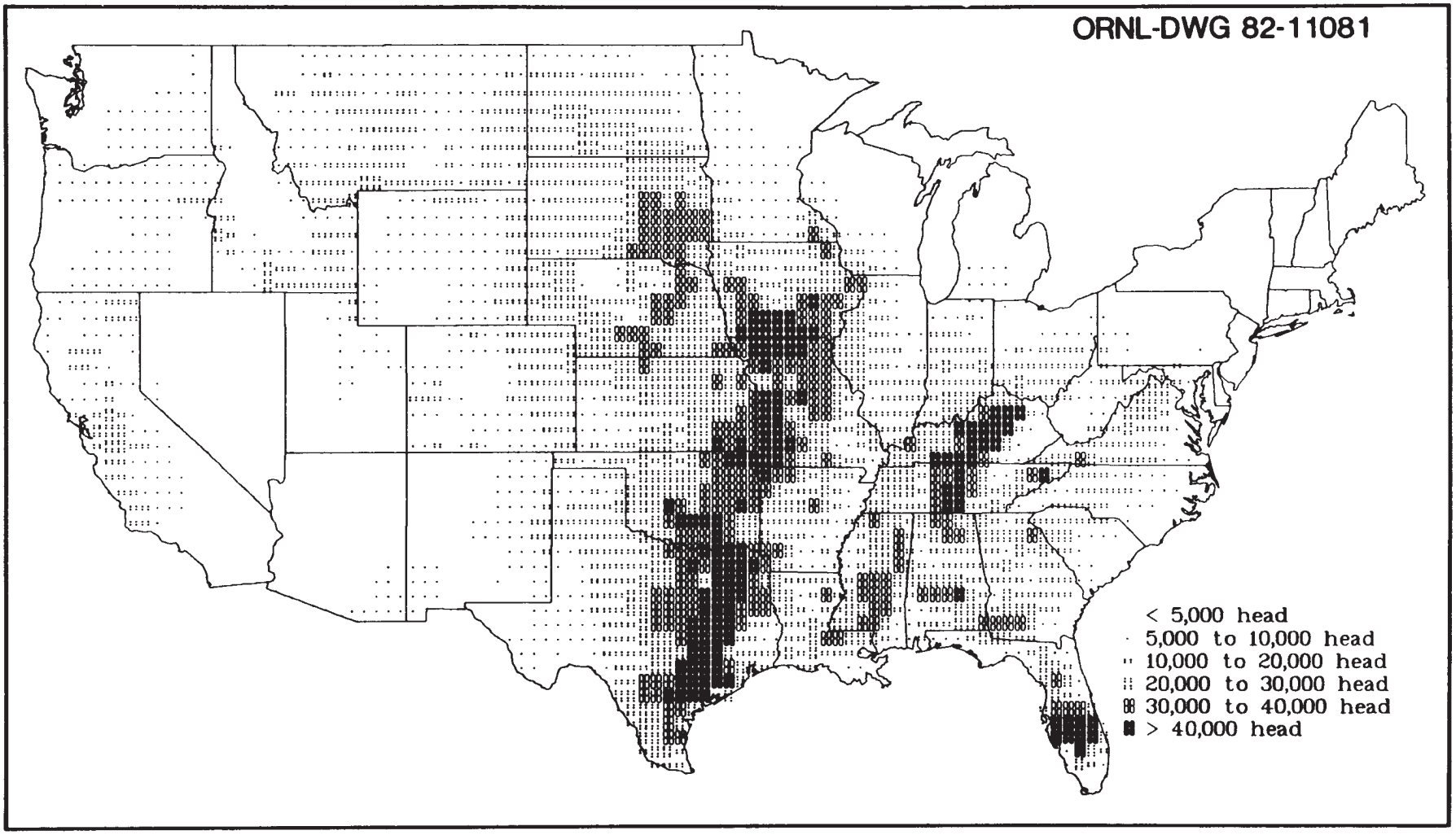


Figure 4.23. Geographic distribution of SITE parameter beef cows inventory, $n_b$.

**Table 4.3. Agricultural and climatological parameters for seven selected SITE cells and parameters derived from them in TERRA**

| Parameter | Cell number; (X,Y); state | | | | | | |
|---|---|---|---|---|---|---|---|
| | #1655 (82,31.5) GA | #2069 (115,33) CA | #2273 (101,34) TX | #3051 (84,37.5) KY | #3182 (91.5,38) MO | #3628 (82.5,40) OH | #4541 (75,44) NY |
| SITE Parameter | | | | | | | |
| $Y_e$ (kg/m$^2$) | 0.536 | 2.28 | 0.577 | 0.721 | 0.154 | 1.13 | 1.29 |
| $Y_{lv}$ (kg/m$^2$) | 0.0 | 2.84 | 0.0 | 0.209 | 0.0 | 2.06 | 0.177 |
| $Y_s$ (kg/m$^2$) | 0.843 | 0.187 | 0.391 | 1.04 | 0.591 | 0.847 | 0.917 |
| $Y_h^a$ (kg/m$^2$) | 0.540 | 1.40 | 0.365 | 0.397 | 0.394 | 0.495 | 0.441 |
| $d_{ff}$ (day/yr) | 287 | 357 | 209 | 201 | 206 | 191 | 162 |
| $A_p$ (m$^2$) | $2.73\times10^8$ | $4.00\times10^7$ | $9.18\times10^8$ | $1.28\times10^9$ | $1.06\times10^9$ | $3.10\times10^8$ | $2.24\times10^8$ |
| $P_s$ (kg/yr) | $6.42\times10^6$ | $2.36\times10^5$ | $4.43\times10^6$ | $1.75\times10^7$ | $5.52\times10^6$ | $1.88\times10^7$ | $3.38\times10^7$ |
| $P_h$ (kg/yr) | $8.54\times10^6$ | $1.61\times10^8$ | $4.01\times10^6$ | $6.97\times10^7$ | $5.70\times10^7$ | $5.97\times10^7$ | $7.22\times10^7$ |
| $n_{cc}$ | 29,536 | 72,784 | 35,451 | 124,414 | 67,263 | 42,645 | 27,564 |
| $n_m$ (head) | 2,446 | 1,460 | 40 | 3,504 | 2,250 | 8,907 | 15,125 |
| $n_s$ (head) | 1 | 34,385 | 1,776 | 3,184 | 444 | 22,226 | 280 |
| $n_b$ (head) | 12,543 | 2,334 | 13,265 | 52,694 | 32,797 | 10,748 | 817 |
| $s_g$ (head) | 2,117 | 136,978 | 1,391 | 3,856 | 2,437 | 6,279 | 127 |
| $P_{gf}$ (kg) | $8.64\times10^7$ | $9.32\times10^6$ | $1.05\times10^8$ | $2.23\times10^7$ | $1.47\times10^7$ | $1.24\times10^8$ | $1.83\times10^6$ |
| Parameters calculated in TERRA | | | | | | | |
| $h_h$ (1/yr) | 5 | 6 | 3 | 3 | 3 | 3 | 3 |
| $Y_h$ (kg/m$^2$) | 0.108 | 0.233 | 0.122 | 0.132 | 0.131 | 0.165 | 0.147 |
| $n_g$ (head) | 1,059 | 68,489 | 696 | 1,592 | 1,219 | 3,140 | 64 |
| $n_a$ (head) | 25,502 | 2334[a] | 34,367 | 119,522 | 63,184 | 29,028 | 12,343 |
| $R_f$ (kg/yr) | $8.81\times10^7$ | $1.00\times10^8$ | $1.06\times10^8$ | $3.80\times10^8$ | $2.02\times10^8$ | $1.40\times10^8$ | $9.83\times10^7$ |
| $C_p$ (kg/yr) | $7.69\times10^7$ | 0 | $9.97\times10^7$ | $3.15\times10^8$ | $1.55\times10^8$ | $8.11\times10^7$ | $1.88\times10^7$ |
| $Y_{pg}^a$ (kg/yr/m$^2$) | 0.282 | 0 | 0.109 | 0.246 | 0.146 | 0.262 | 0.084 |
| $g_{pg}$ (1/yr) | 10 | 0 | 7 | 7 | 7 | 6 | 5 |
| $Y_{pg}$ (kg/m$^2$) | 0.028 | 0 | 0.016 | 0.035 | 0.021 | 0.044 | 0.017 |

[a]Set equal to inventory of beef cattle in this SITE cell.

$$f_{gi} = 1 - \frac{P_{gf}}{R_g}, \tag{45}$$

unless $P_{gf} / R_g > 1.0$, in which case $f_{gi}$ is set to 1.0.

Table 4.3 lists 13 of the 14 agricultural parameters in SITE and number of frost-free days, which is used by TERRA for selected SITE cells in the United States. The 14$^{th}$ agricultural parameter, irrigation, is discussed in Sect. 4.2. The other seven parameters—annual yields (production) of leafy vegetables, $P_{lv}$, exposed produce, $P_e$, protected produce, $P_{pp}$, grains consumed by man, $P_{gh}$, and productivity estimates for protected produce, $Y_{pp}$, grain feeds, $Y_{gf}$, and grain foods consumed by man, $Y_{gh}$,—are not currently used by TERRA.

## 4.2 Climatological Parameters

The SITE data base contains six climatological parameters—precipitation, evapotranspiration, absolute humidity, morning mixing height, afternoon mixing height, and number of frost-free days. All except evapotranspiration have been calculated according to the method described in Sect. 4. for climatological parameters (interpolation among the three nearest weather stations).

Evapotranspiration was calculated by United States county and converted to SITE cell basis according to Method B. Of the six, only precipitation, evapotranspiration, absolute humidity, and frost-free days are used by TERRA. Frost-free days has been discussed in Sect. 4.1. The following discussion will detail the derivation and use of the remaining five climatological parameters and the agricultural parameter irrigation.

Evapotranspiration (Fig. 4.24), irrigation (Fig. 4.25) and precipitation (Fig. 4.26) are used in the calculation of leaching constants [Eq. (7)] as described in Sect. 2.4. Leaching constants are calculated for both irrigated and nonirrigated soils in TERRA. Food crops (except grains) are assumed to be grown on irrigated soils and all livestock feeds are assumed to be grown on nonirrigated soils. The numerator of Eq. (7), $(P+I-E)$, is assumed to be a mass balance of water inputs and outputs for a given agricultural area. Surface runoff and storage of water in surface agricultural soils is not considered in TERRA.

Evapotranspiration was calculated according to a model proposed by Morton.[216] The model requires as input annual precipitation, sea level pressure (or altitude), monthly dew point, monthly ambient air temperatures, and monthly fraction of maximum possible sunshine. Annual precipitation was taken from Olson, Emerson, and Nungesser[217] by county in eastern states and by state climatic division in western states. Conversion of precipitation by state climatic division to a county basis was achieved using the IUCALC code.[215] The altitude of each county centroid in meters was estimated using the TERGHT code.[218] Each altitude was converted to sea level pressure in millibars using[219]

$$P_{sl} = \left[ \frac{z - 44308}{-11876.94} \right]^{5.25679} , \tag{46}$$

where

$P_{sl}$ = sea level pressure (mb) and
$z$ = altitude (m).

Monthly dew point and ambient air temperatures were taken from references 210, 211, and 212 for various United States weather stations. The monthly fractions of maximum possible sunshine were taken from references 211 and 212 for various weather stations. All parameters derived from weather station data were interpolated to county centroids and finally to the half degree cells using methods previously described.

Annual irrigation in centimeters was taken from information reported in the 1974 Census of Agriculture. For each county the 1974 Census reports total land irrigated in acres and the estimated quantity of irrigation water applied in acre-feet. The latter was divided by the former and the quotient was converted to centimeters.

Irrigation was not included with precipitation in the model input parameters, although it is considered in Eq. (7). This discrepancy will add a small amount of error to the evapotranspiration by county calculation. Because the Morton model is designed for large land areas and does not provide for local discontinuities, it was assumed that irrigation water is an insignificant fraction of total precipitation over the entire county or cell. This assumption is supported by the observation that nationally only 3-4% of all farmland is irrigated. However, in some counties irrigated land may be a significant fraction of the total land area and our calculations inappropriate.

According to Morton, the evapotranspiration model has been verified over a wide range of environments and compares satisfactorily with annual precipitation less runoff for 81 river basins in Canada, 36 river basins in the southern United States, three river basins in Ireland, and two river basins in Kenya. Wallace[220] compared the model with the Thornthwaite-Mather[221] and Penman[222] approaches to modeling evapotranspiration and found the Morton model to be superior in modeling arid environments. Morton, however, warns against use of the model near sharp environmental discontinuities. Therefore, estimates of evapotranspiration near coast-lines and mountain ranges are suspect.

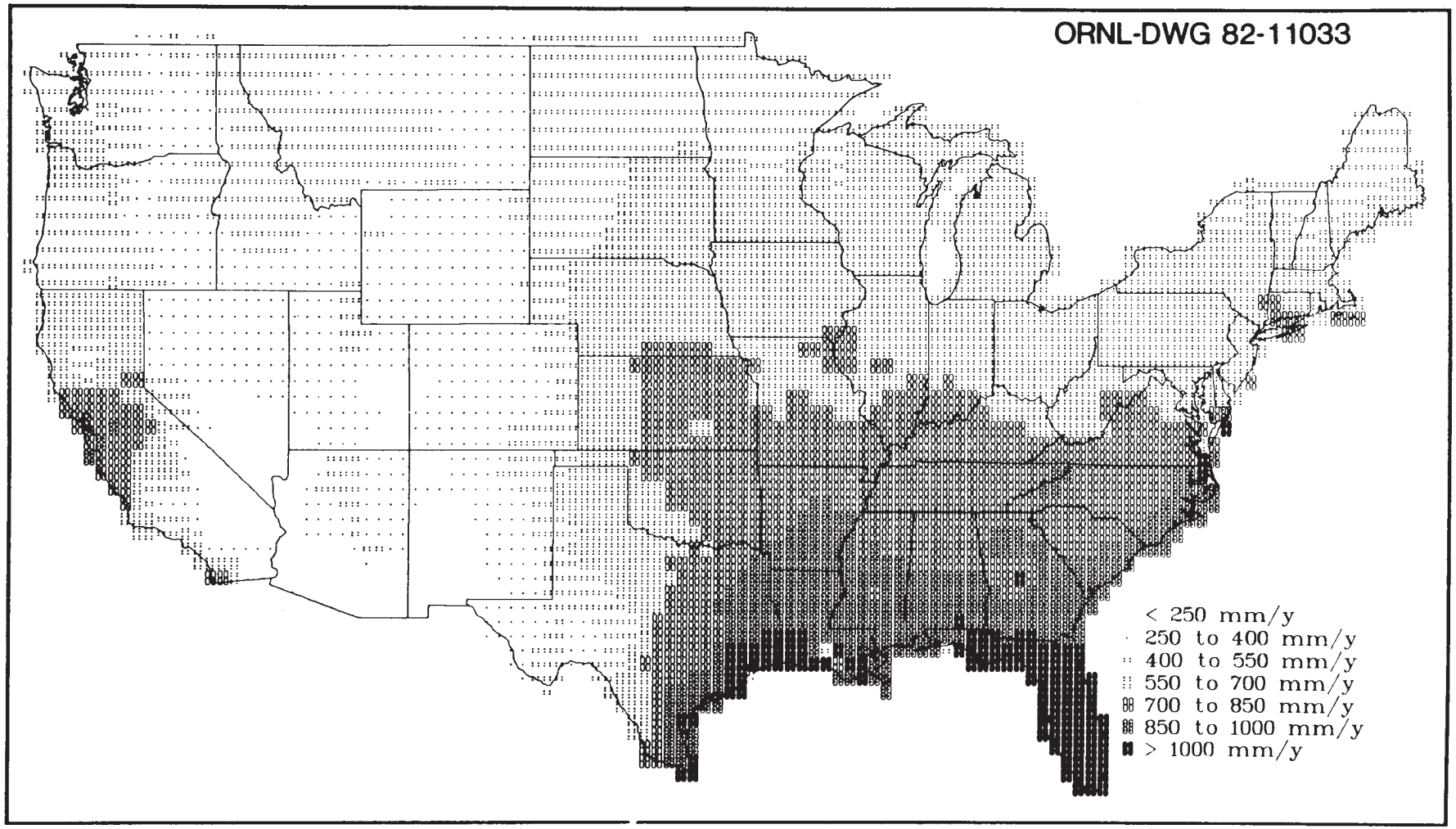


Figure 4.24. Geographic distribution of SITE parameter estimated annual average evapotranspiration, *E*.

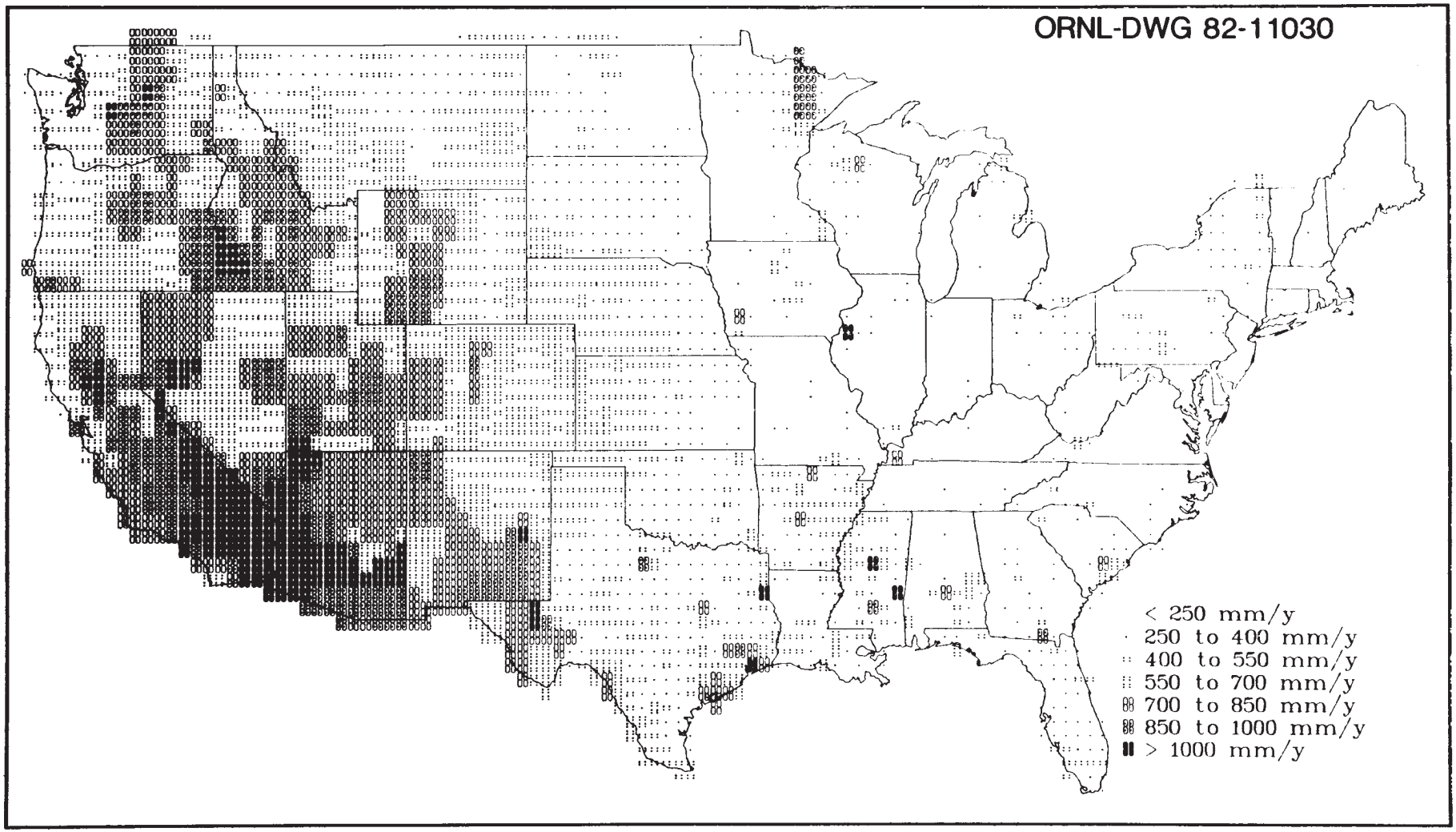


Figure 4.25. Geographic distribution of SITE parameter estimated annual average irrigation, *I*.

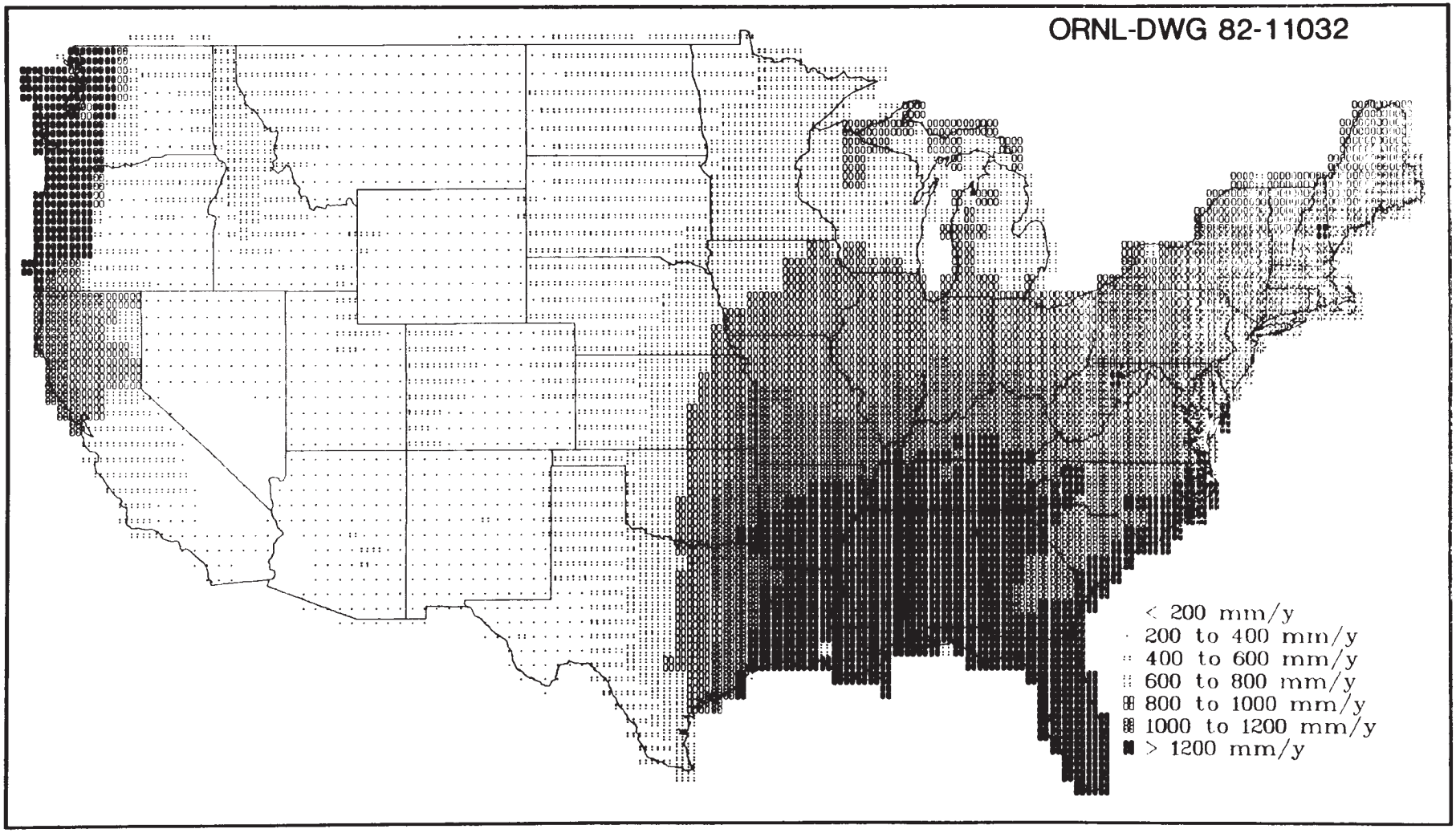


Figure 4.26. Geographic distribution of SITE parameter estimated annual average precipitation, *P*.

Morning and afternoon mixing heights in meters (Figs. 4.27 and 4.28, respectively) were taken from the annual average tabulation for 62 United States weather stations reported by Holzworth[223] under both precipitation and nonprecipitation conditions. Cell values are interpolations among the three nearest weather stations. Currently, morning and afternoon mixing height estimations are not used in TERRA. However, they may be of use to atmospheric dispersion computer codes and models which calculate dispersion of elevated releases.

The estimates of absolute humidity (Fig. 4.29) were taken from the annual averages for 218 United States weather stations calculated by Etnier[224] from annual-average temperature and relative humidity data. The cell-averaged values were interpolated from the three nearest weather stations as previously described.

### 4.3 Demographic and Miscellaneous SITE Parameters

In addition to the 29 parameters previously discussed, SITE includes seven parameters describing the population of the cell and cell characteristics. These parameters include the estimated 1980 population and fractions (based on the 1970 Census) which are classified as urban, rural-farm, and rural-nonfarm, the actual land area of the cell, the dominant land feature in the cell, and the coarse suspended particulate matter due to resuspension.

The 1980 population estimate for half degree cells (Fig. 4.30) was determined from data by enumeration district as described in references 213 and 214. The definitions of “urban,” “rural-farm,” and “rural-nonfarm” are as follows. The urban population (Fig. 4.31) comprises all persons living in (1) places of 2,500 inhabitants or more incorporated as cities, boroughs, villages, and towns (except towns in New England, New York, and Wisconsin); (2) the densely settled urban fringe, whether incorporated or unincorporated, of urbanized areas; (3) towns in New England and townships in New Jersey and Pennsylvania which contain no incorporated municipalities as subdivisions and have either 25,000 inhabitants or more or a population of 2,500 to 25,000 and a density of 580 persons or more per square kilometer (1,500 persons per square mile); (4) counties in states other than the New England States, New Jersey, and Pennsylvania that have no incorporated municipalities within their boundaries and have a density of 580 persons or more per square kilometer (1,500 persons per square mile); and (5) unincorporated places of 2,500 inhabitants or more. The rural population is divided into “rural-farm,” (Fig. 4.32) comprising all persons living on farms, and “rural-nonfarm,” (Fig. 4.33) comprising the remainder. According to the 1970 Census definition, the farm population consists of all persons living in rural territory on places of less than 0.04 $km^2$ yielding agricultural products which sold for $250 or more in the previous year, or on places of 0.04 $km^2$ ( 10 acres) or more yielding agricultural products which sold for $50 or more in the previous year.

The land area of the cell in square meters is less than or equal to the theoretical area of the cell, depending on the area of surface waters in the cell. The actual area of the cell was determined from the county areas reported in the 1974 Census of Agriculture. “Land areas” includes land temporarily or partially covered by water (marshlands, swamps, etc); canals under 201 m (one eighth statute mile) wide; and lakes, reservoirs, and ponds under 0.16 $km^2$ (40 acres).

The SITE data base contains a coded number which describes the dominant land feature of the cell (Fig. 4.34). The dominant land feature may be useful to atmospheric dispersion calculations requiring location-specific surface roughness correction factors. The dominant land features considered are

1) Tall row crops,
2) Short row crops,
3) Hay or tall grass,
4) Urban areas,
5) Small lakes,
6) Short grass, and
7) Forest.

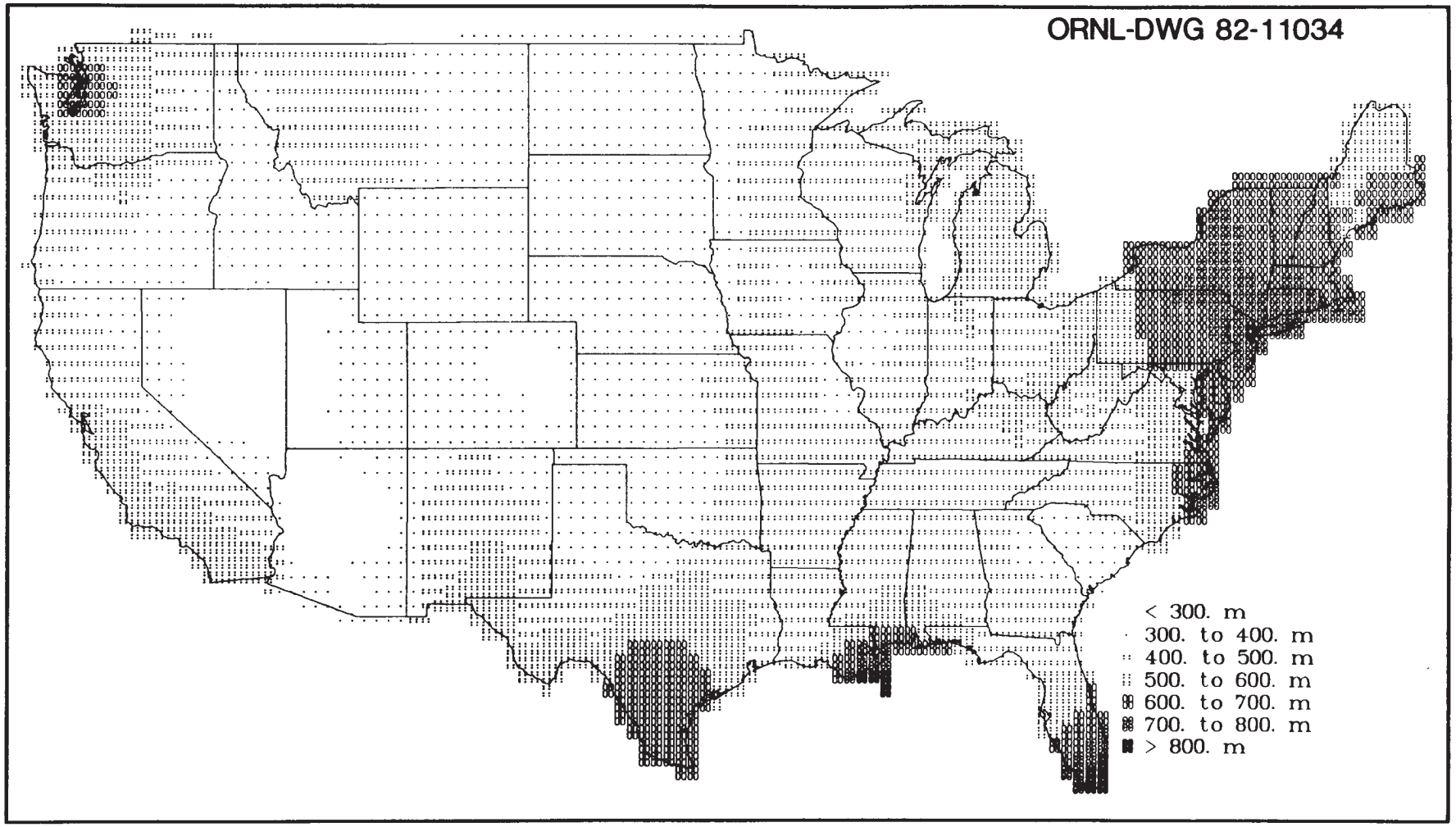


Figure 4.27. Geographic distribution of SITE parameter estimated annual average morning mixing height, $M_{am}$

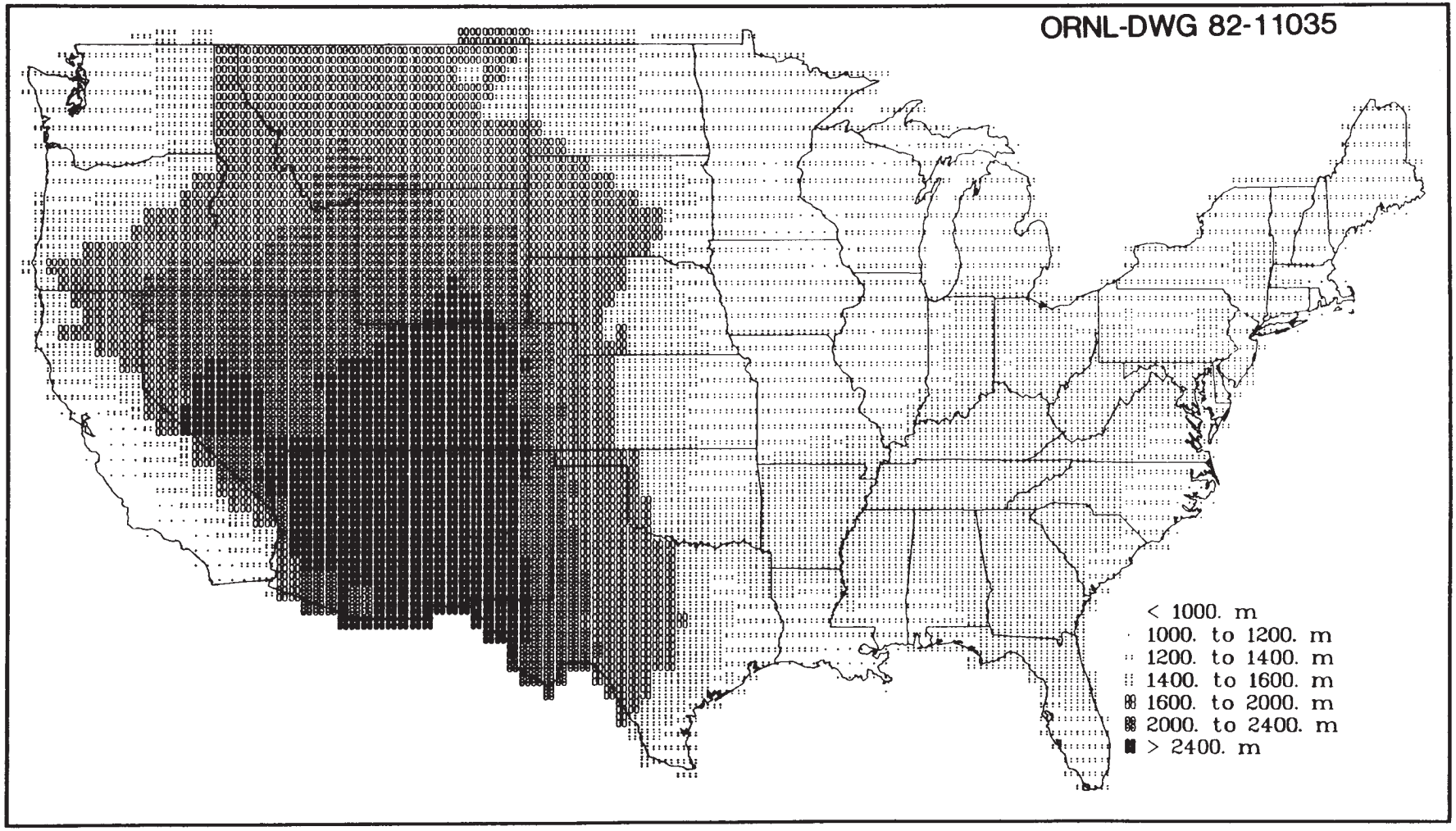


Figure 4.28. Geographic distribution of SITE parameter estimated annual average afternoon (evening) mixing height, $M_{p\ m}$

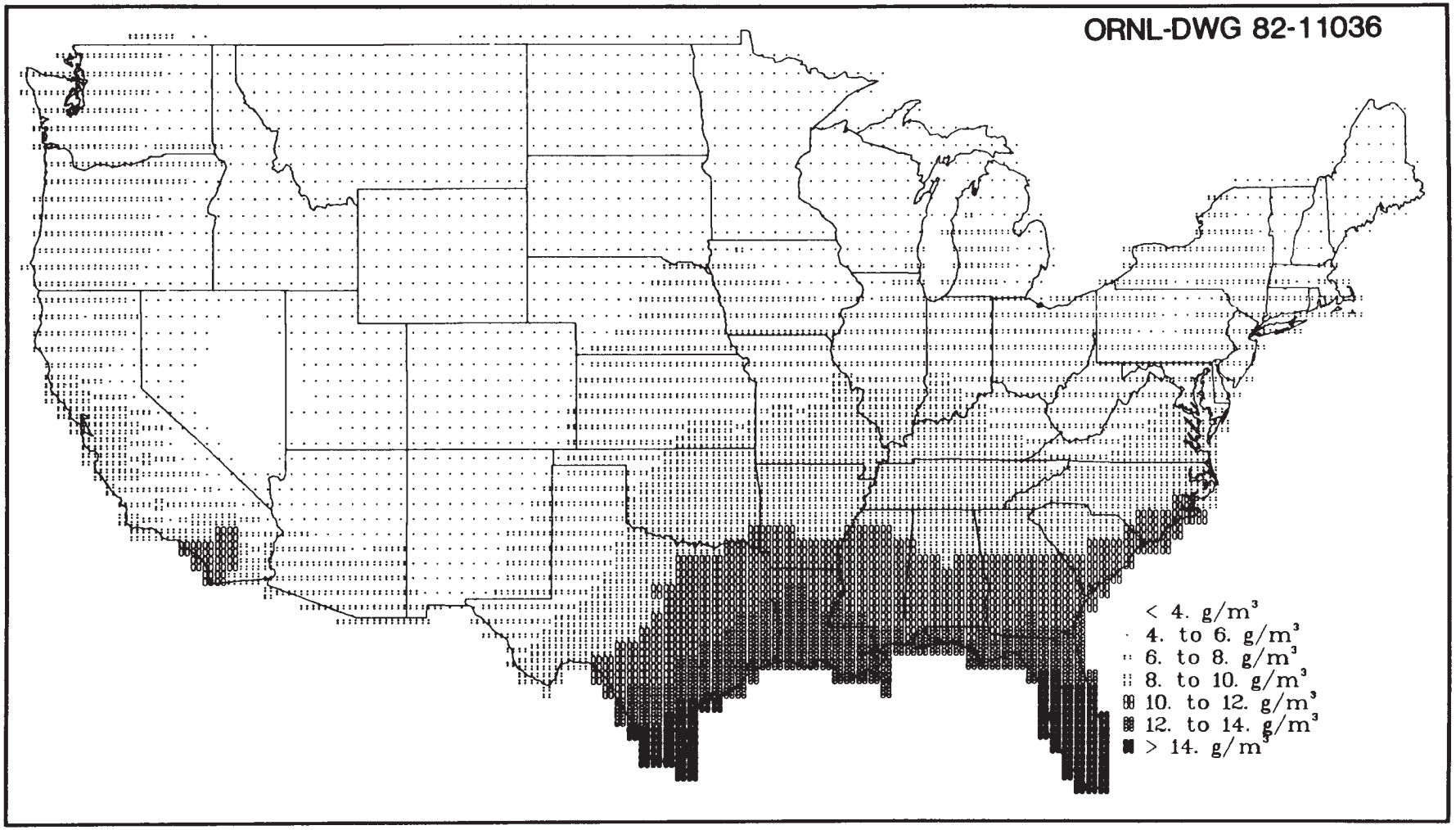


Figure 4.29. Geographic distribution of SITE parameter estimated annual average absolute humidity, *H*.

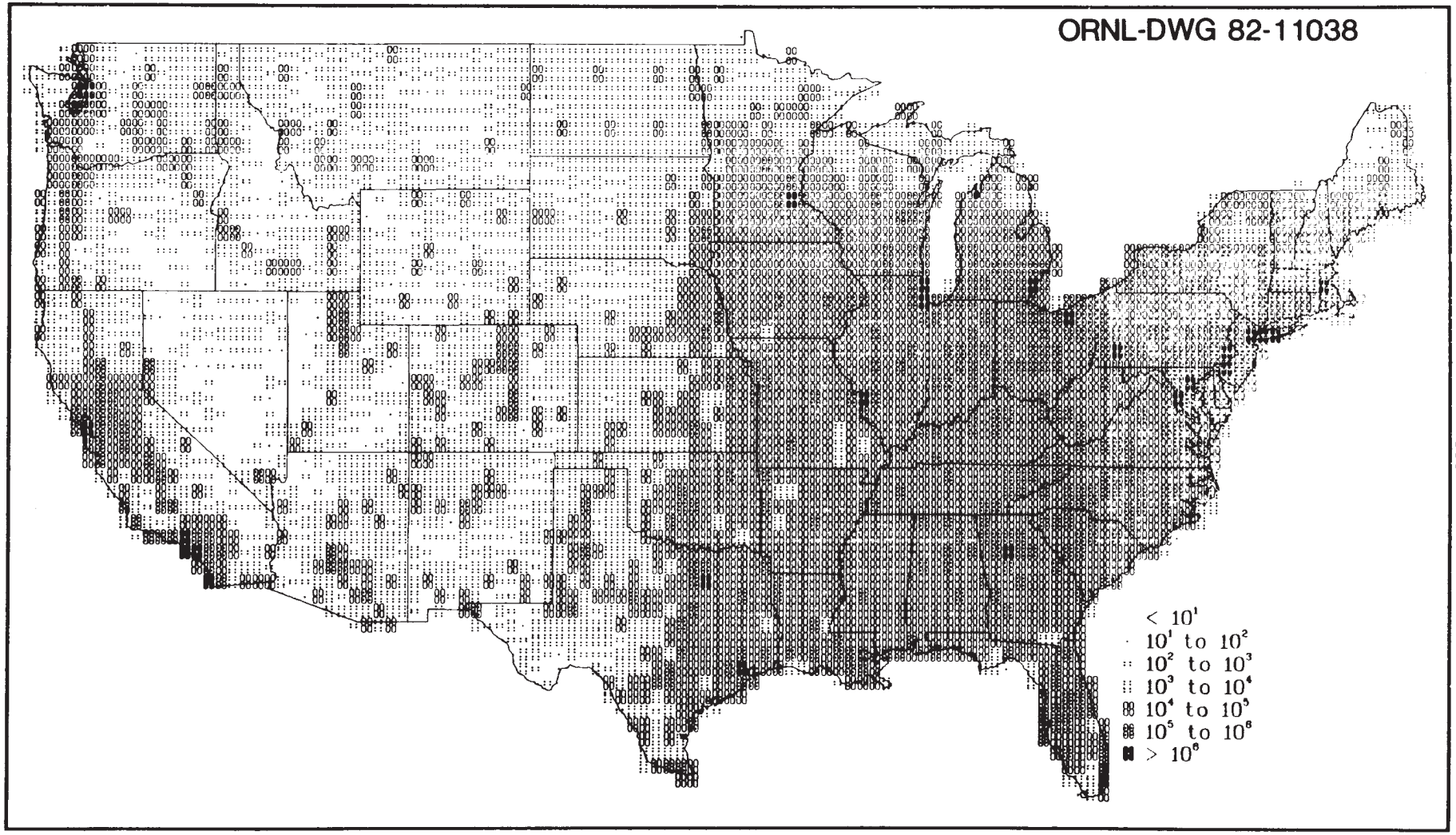


Figure 4.30. Geographic distribution of SITE parameter (estimated 1980) U.S. population, $pop_i$.

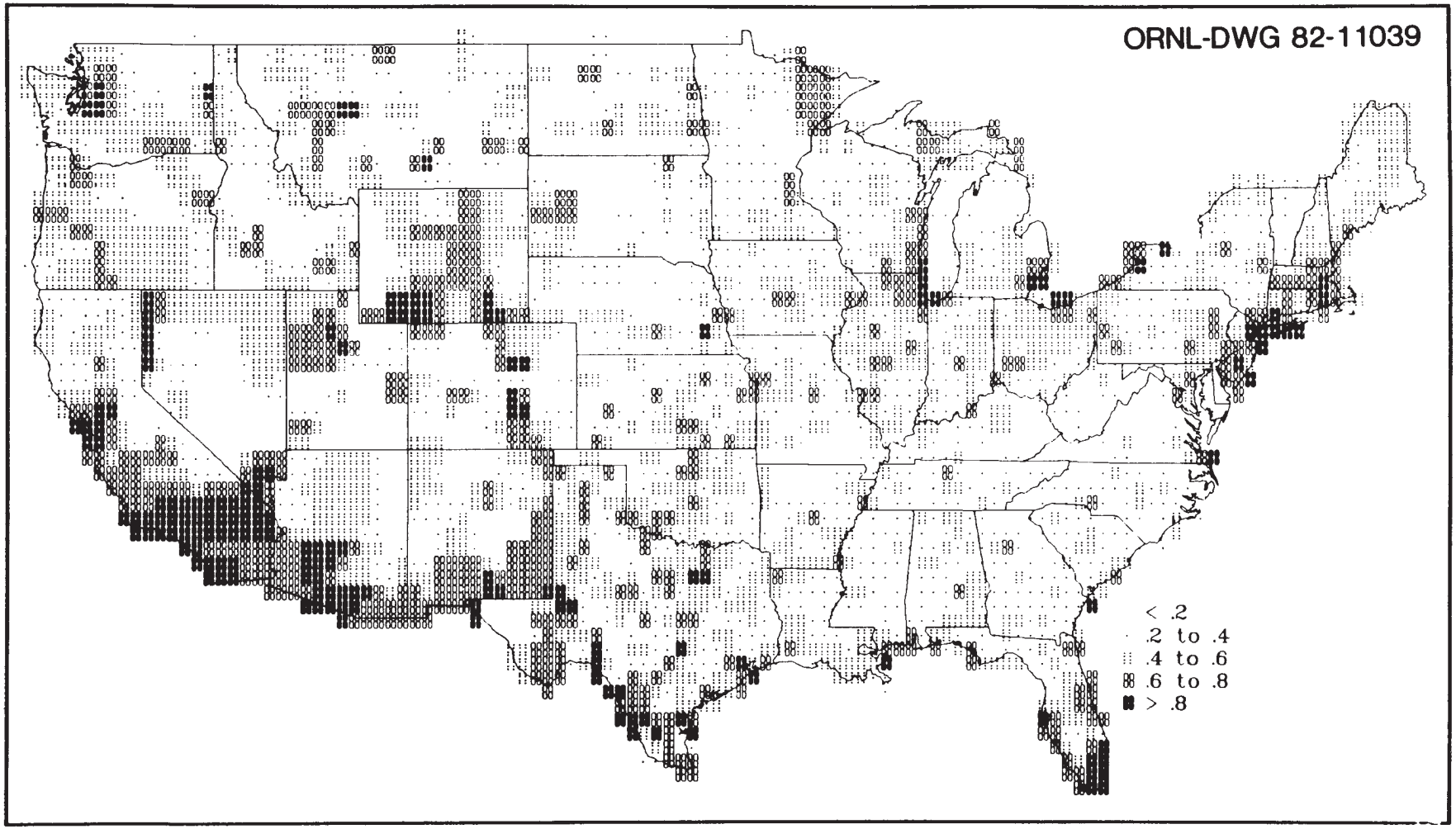


Figure 4.31. Geographic distribution of SITE parameter fraction of (1970) population classified as urban, $pop_u$.

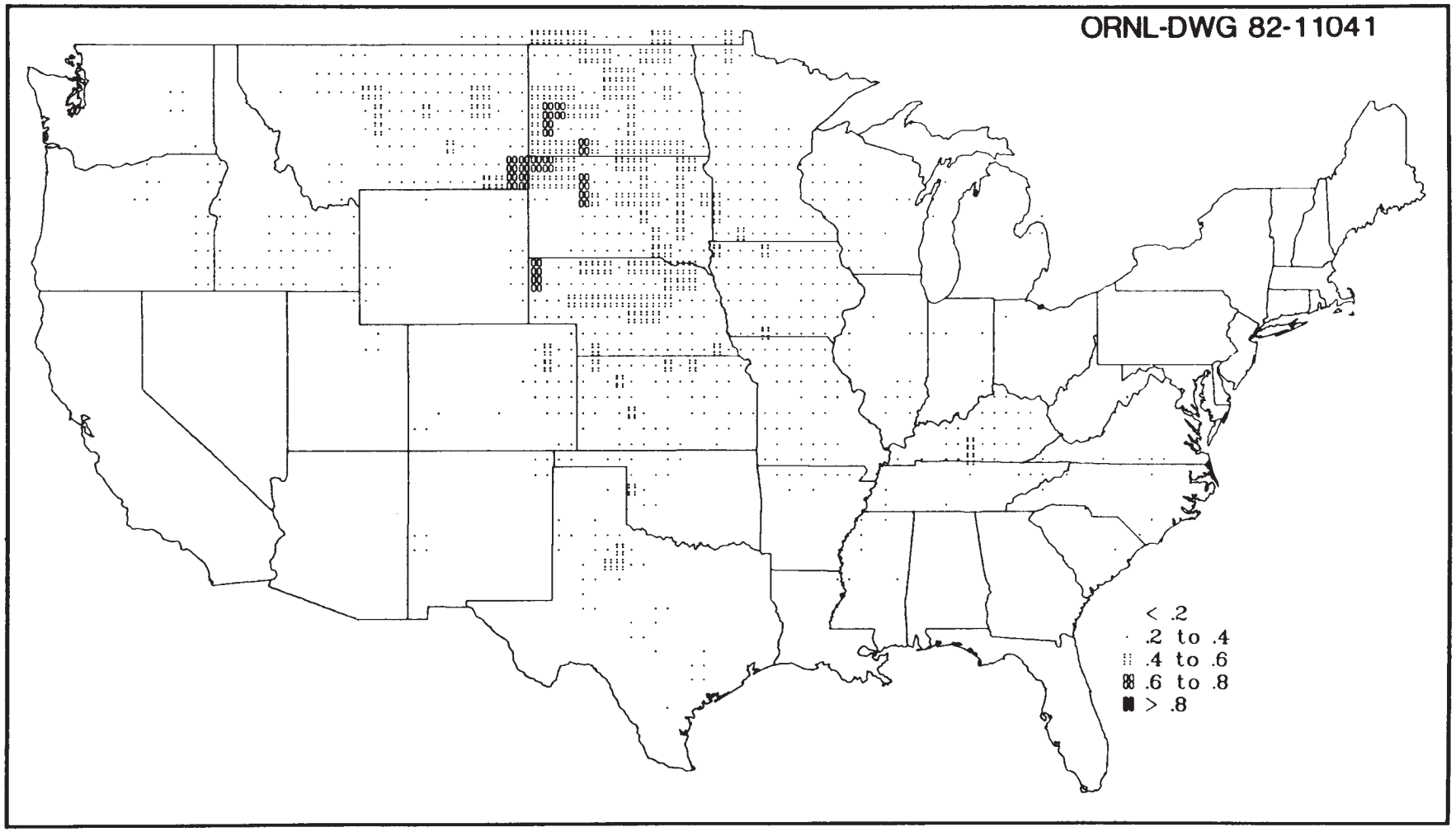


Figure 4.32. Geographic distribution of SITE parameter fraction of (1970) population classified as rural-farm, $pop_{rf}$.

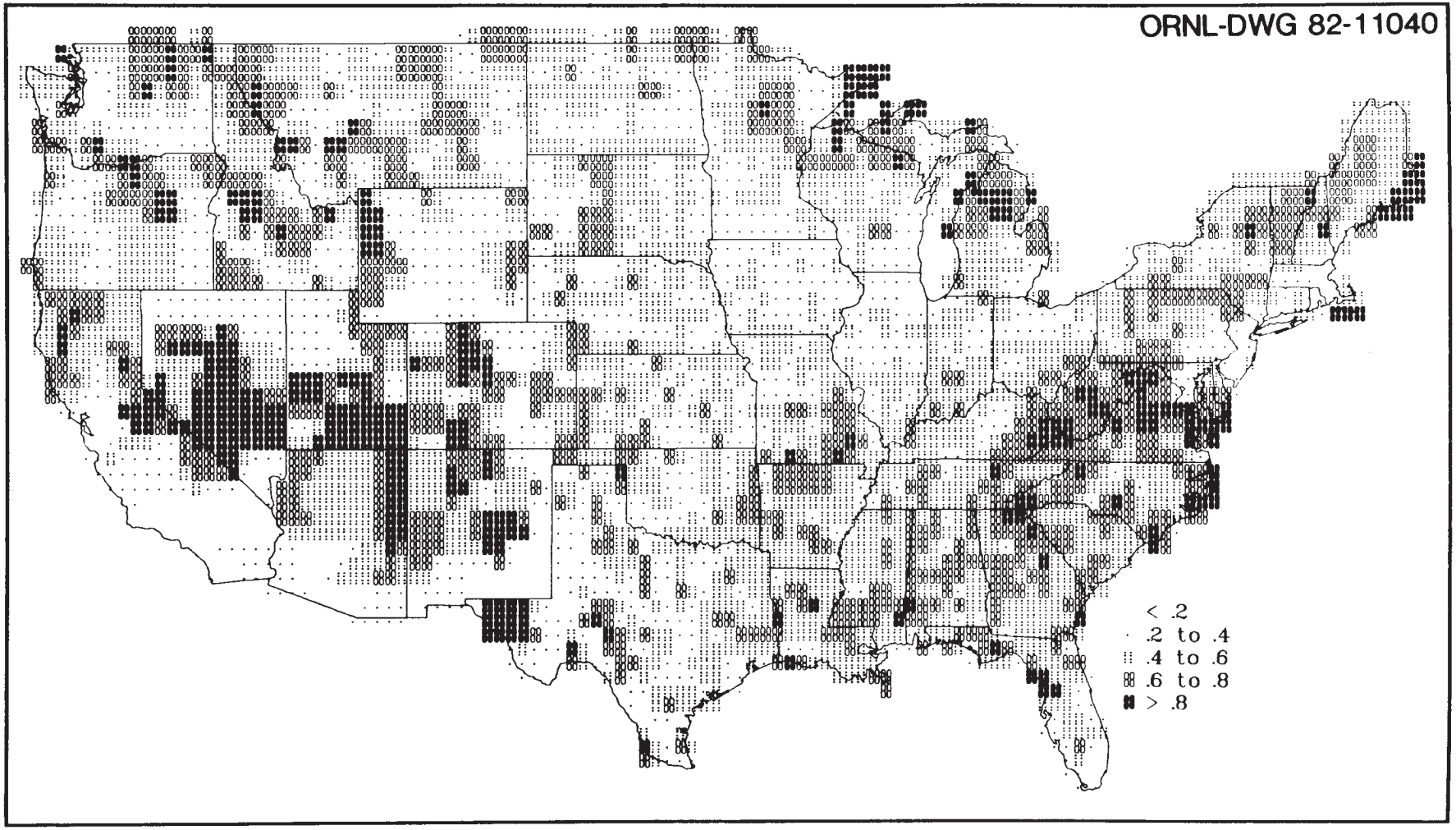


Figure 4.33. Geographic distribution of SITE parameter fraction of (1970) population classified as rural-nonfarm, $pop_{nf}$

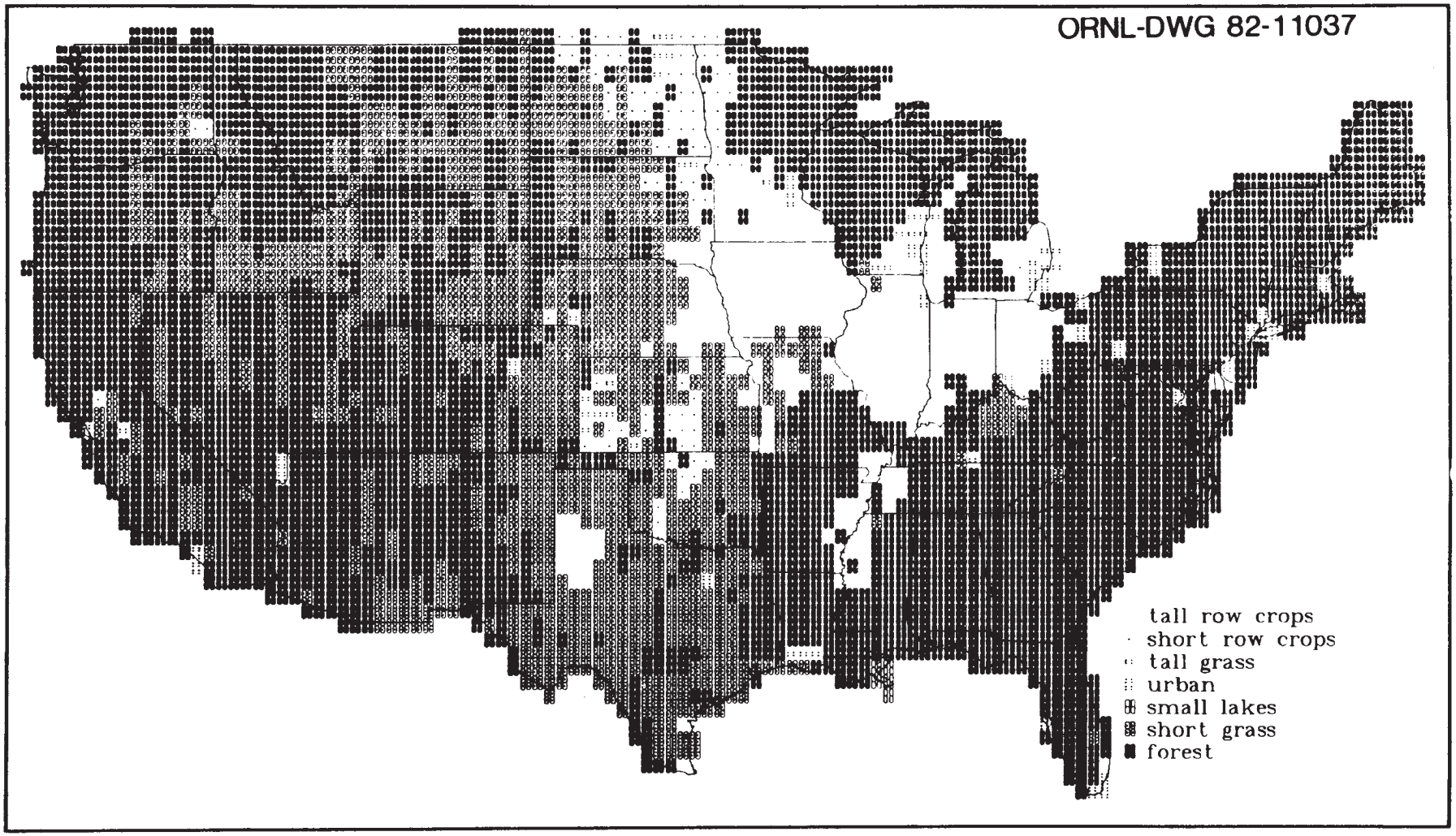


Figure 4.34. Geographic distribution of SITE parameter dominant land feature, $L_{d\,f}$

The dominant land features were determined from data gathered by Olson, Emerson, and Nungesser.[217] They reported areas for each land feature by county. The county areas were converted to cell areas by methods previously described. The land feature with the largest area is considered the dominant land feature.

The dominant land feature is expressed as a code of the form FLPPP. The “F” value is either “0” or “1,” for less than or more than 50% of the total area in the cell classified as Federal land, respectively. Federal land was not subclassified as to land use in data gathered by Olson, Emerson, and Nungesser.[217] Therefore, an assumption inherent in our estimation of dominant land feature is that Federal and privately owned lands are similar in land feature make up. This assumption may be incorrect, especially when Federal lands are protected forest or wildlife areas. The “L” value corresponds to the seven land features previously given. The “PPP” value indicates the percentage of the total area of the cell corresponding to the “L” category.