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TARO CORM SPECIFIC GRAVITY RESPONSE

TO

HARVEST AGE AND SOIL TYPE

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ABSTRACT

Identifying low-input, sustainable practices that affect taro [Colocasia esculenta (L.) Schott] corm specific gravity may lead to improved corm quality for market in developing countries and for processing into a wide range of food products. Investigations of the relationship between high specific gravity and improved tuber quality for the Irish potato (Solanum tuberosum L.) indicate soil type and harvest age affect tuber specific gravity. This study examines the effects these two factors may have on increasing corm specific gravity. During the first of two years about 1000 taro plants, cv. Niue, were grown on each of 3 soil types (Leafu clay, very fine, mixed, Cumulic Hapludoll; Oloava loam, medial over cindery, Typic Dystrandept; and Puapua sandy clay loam, medial over cindery, Lithic Eutrandept) at American Samoa, with harvests made after 6, 7, 8, and 9 months. The following year 64 plants were grown for 6 months at each of 6 sites (that included the above soil types plus Sogi sandy loam, medial, Udic Eutrandept and two sites with soils classified as Pavaiai, medial-skeletal, Typic Dystrandepts). Specific gravity was determined on individual corms using a modified air and water method. Soil texture was found to correlate with corm specific gravity. Loams may produce inferior quality corms by lowering specific gravity, while clayey soils increase it. Harvest age also affects specific gravity, but in an unpredictable way due to unidentified, site-specific factors. Corm specific gravity is only weakly correlated with corm weight, suggesting that factors influencing one may not necessarily influence the other.

Taro, *Colocasia esculenta* (L. Schott, is a major food throughout the tropics and subtropics. In the Pacific, corms are peeled, washed, boiled or baked, and served with fish, poultry, pork or beef. In Hawaii, Tahiti, and the Cook Islands, a paste ('poi' in Hawaii) is made from boiled and fermented taro. From a nutritional point of view, taro compares well with other root crops such as yam, cassava, and sweet potato, and with rice (Lambert, 1982 It has excellent potential in the snack chip and baby food markets, and in the production of flour. One obstacle to expanding its commercial uses is a scarcity of information regarding the effects of production practices on corm quality.

Quality, for fresh corms and poi, may refer to taste, texture, and appearance; for processing, high starch content, chemical composition, and other attributes might be considered

For the Irish potato, *Solanum tuberosum* L., specific gravity is the best single criterion of tuber quality (Teich and Menzies, 1964 It is directly related to the total solids, starch content, and mealiness of tubers (Murphy and Goven, 1959) Specific gravity also
method for evaluating corm quality in taro, with high

specific gravity corresponding to high quality (Bowers, *et al.*, 1964).

Much attention has been given to the effects the major plant nutrients have on potato specific gravity. Excess nitrogen decreases tuber specific gravity consistently, while normal levels of nitrogen, phosphorus, or potassium may either increase, decrease, or have no effect on specific gravity (Kundel and Holstad, 1972; Munro, *et al.*, 1977; Murphy and Goven, 1959; Teich and Menzies, 1964). Where, for economical or environmental reasons, fertilizer inputs to increase specific gravity may not be feasible, low-input, sustainable methods would be preferred. A number of inherent soil properties are thought to influence in some way the specific gravity of potatoes produced in any soil (Murphy and Goven, 1959), and this may also hold true for taro.

In Samoa, it is commonly believed that the size of the taro corm is affected by the size of the planting hole. Investigation has shown that both corm yield and quality (evaluated by a taste test) are affected by the planting-hole size, with larger holes generally producing larger corms of better quality (Cable and Asghar, 1983). Since the planting-hole size is roughly equivalent to the volume of soil whose structure has been disturbed, this suggests that soil structure may influence corm quality.

This study examines the effects soil type (3 the first year; 6 the second) and harvest age (6 to 9 months during the first year only) have on corm specific gravity of upland, rain-fed taro grown on the porous basaltic soils of humid, tropical Samoa.

MATERIALS AND METHODS

First Year

In October, 1988, taro cv. Niue (or less commonly, Niue-ulaula, Whitney, *et al.* 1939), a dasheen type with a large central corm and few suckers, was planted at 3 sites on Tutuila Island, American Samoa (Table 1). After slashing, conical holes 25 to 30 cm deep and 70 to 90 cm apart were dug using a long pointed pole. A sett ('tiapula' in Samoa), consisting of a centimeter or so of the corm apex and 40 to 60 cm of the petioles without their leaf blades (Fig. 1), was dropped into each hole and lightly tamped into the soil. By 10 weeks rains filled the holes with loose soil.

At 6, 7, 8, and 9 months after planting, about 115 kg of corms were harvested at each site. Traditionally, corms are cut just beneath the apex to retain a planting sett. In this study a centimeter or so of the petiole base was allowed to remain attached to the corm to attenuate deterioration.

Corm specific gravity was determined using a modification of the air and water method (Murphy & Goven, 1959) to counteract corm buoyancy. After washing, every tenth corm was weighed, then suspended in water and weighed again while attached by a velcro strap to a 700 g weight. Specific gravity was calculated as:

$$SG = W_A * SG_W / [W_A - (W_B - W_C)] \qquad \text{[Eq. 1]}$$

where
- SG is corm specific gravity
- W_A is corm weight, in grams
- SG_W is specific gravity of the water at room temperature, measured with a hydrometer.
- W_B is the sum of the corm, lead, and strap weights, in grams, while submerged in water
- W_C is the sum of the lead and strap weights, in grams, while submerged in water

The maximum possible error in SG, ΔSG, was determined from its total differential:

$$\Delta SG = [\delta SG/\delta W_A]\Delta W_A + [\delta SG/\delta SG_W]\Delta SG_W + [\delta SG/\delta(W_B - W_C)]\Delta(W_B - W_C) \quad \text{[Eq. 2]}$$

where

$$[\delta SG/\delta W_A] = -[(W_B - W_C) SG_W]/[W_A - (W_B - W_C)]^2$$

$$[\delta SG/\delta SG_W] = W_A/[W_A - (W_B - W_C)]$$

$$[\delta SG/\delta(W_B - W_C)] = W_A SG_W/[W_A - (W_B - W_C)]^2$$

$$\Delta W_A = 1 \text{ g}$$

$$\Delta SG_W = 0.001$$

$$\Delta(W_B - W_C) = 2 \text{ g}$$

The experimental setup was a completely randomized two-way classification with 15 observations per cell (Snedecor and Cochran, 1989). Specific gravities of 15 corms, selected at random from each combination of site (3 levels) and harvest age (4 levels), were analyzed. The harvest at site A during month 7 inadvertently included taro of unknown history from an adjacent field. Observations from this combination of treatments, therefore, were invalid. Two ANOVA were performed on the remaining data: one excluding data from site A and a second excluding data from month 7.

Second Year

At roughly weekly intervals between October 27 and December 14, 1989, sixty-four Niue setts were planted 60 cm apart on an 8-plant by 8-plant grid at six sites (Table 2). The ground was cleared of vegetation and 30 g of 12-8-16-17(S)-0.5(Zn) slow-release fertilizer were placed in each hole and covered with a few centimeters of soil before planting the setts. Ten grams of a soluble 10-52-8 fertilizer were placed along the rim of each hole and were washed inside, together with loose soil, with the first rain. At 8 and 14 weeks 15 g of the 12-8-16 fertilizer were placed in a ring 2 to 5 cm from the petiole and covered lightly with soil. Sites were kept weed-free by hoeing between rows and hand weeding around plants. Armyworms, *Spodoptera litura*, and giant African snails, *Achatina fulica*, were removed from the plants and rainfall recorded from a 150-mm capacity gauge during weekly inspection.

Corms were harvested after 6 months and separated into two groups: those from the outside, or border rows and those from the 6-plant by 6-plant interior rows. After specific gravity measurements for both groups, those from the border rows had their petiole base removed by cutting just beneath the corm apex. Their specific gravities were then measured again.

Because of heterogeneous variances, an ANOVA was not performed on the specific gravity distributions of corms from the interior rows. Instead, analysis was confined to testing means for correlation with soil factors and speculating on the nature of the relationship.

Soil Tests

During the first year, the soil testing laboratory was not fully operational, so only a few tests were made (Table 1). This section describes soil testing for the second year (Table 2) but pertains, where applicable, to the first year also.

Before planting, eight to ten 20-cm deep soil cores were systematically taken and consolidated into a single sample for each site. Samples were air-dried, passed through a 2-mm sieve, and stored for testing. Unless otherwise specified, analyses were conducted on air-dried soil but with nutrient levels based on oven-dry (105 °C) weight.

Soil texture was determined on oven-dried soil by the Bouyoucos method. Soil pH was measured using 1:1 soil:distilled water. Neutral 1 N ammonium acetate was used to extract exchangeable cations. Calcium (422 nm) and magnesium (285 nm) determinations were made by atomic absorption spectroscopy; potassium (766 nm) and sodium (589 nm) determinations were by atomic emission spectroscopy, all using an air-acetylene flame. Cation exchange capacity was measured by steam distilling an alkaline slurry of the ammonium acetate-saturated soil, collecting the distillate in 2% boric acid solution, and titrating with 0.10 N hydrochloric acid to determine the ammonium in the distillate. Soil phosphorus was determined by treating a modified Truog (0.02 N H_2SO_4, pH 2, 1:100 soil:solution) extract of the soil with ammonium paramolybdate and measuring optical density at 660 nm (Ayers and Hagihara, 1952). Soil organic carbon was assayed by the Walkley-Black procedure on oven-dried soil. Soil nitrogen was determined using a permanganate-reduced iron modification of the Kjeldahl method to include nitrate and nitrite (Bremner and Mulvaney, 1982). Electrical conductance was measured on a 1:2 soil:distilled water slurry.

RESULTS AND DISCUSSION

Because data from site A, month 7 of the first year of the study included spurious observations, two ANOVA were performed on the remaining data: one excluding data from site A (Table 3), and another excluding data from month 7 (Table 4). Both indicate that very highly significant differences (P <

0.001) exist between sites. Significant interactions in both tables preclude any overall statement that could be made from the main effects.

Comparing the specific gravities of corms from sites B and C over all 4 harvest ages shows a marked increase in the specific gravity distribution at 9 months compared to 6 months, but no consistent increase over time (Fig. 2). This is particularly true when site A is also considered. The fluctuations of specific gravity distribution means at each site over time suggest some unidentified, dynamic, site-specific factor(s) is influencing corm specific gravity.

Specific gravity was consistently lower over all months at site B in the between-sites comparison. The major differences in soil properties at site B compared with sites A and C were a higher pH, a preponderance of sand constituting soil texture, and a larger Ca:Mg ratio. When these and other factors were compared with the mean corm specific gravity at each site for the second year, only the percentage of sand composing soil texture exhibited any significant correlation (Fig. 3).

It seems reasonable that a heavy-textured soil would resist expansion of the growing corm, while a light-textured soil would exert less resistance. Consequently, production on a clayey soil would be expected to give corms of higher specific gravity than on a sandy soil under similar conditions. Therefore, an inverse relationship between corm specific gravity and the proportion of sand constituting soil texture would be expected. But the empirical curve fitting the data of Fig. 3 cannot be explained solely by differences in the compressibility of soils of different texture. It suggests a more complex relationship exists between corm specific gravity and soil texture, with loams (30 to 50% sand) producing corms of minimal specific gravity.

Although corm specific gravity and corm weight are related (Eq. 1), they are weakly correlated (Fig. 4). The coefficient of linear correlation, $r = 0.085$, is significant at the 5% level for a one-tailed test, suggesting corm specific gravity is not entirely independent of corm weight. But the coefficient of determination, r^2, indicates that less than 1% of the variance in specific gravity is explained by corm weight. Neither the nearly random distribution of points on the scatterplot nor the trend curve suggests an alternative relationship that would provide a better fit. This suggests factors that influence corm weight may not necessarily affect corm specific gravity. Otherwise, if both correlate strongly with a common factor, they should correlate strongly with one another. This near-absence of correlation between specific gravity and weight is also seen for the potato (Meredith, personal communication). This may account for the fact that, for potato tubers, reasonable levels of applied nitrogen, potassium, and phosphorus will increase yield but may not affect tuber specific gravity.

Although corm weight only weakly correlates with corm specific gravity, it strongly correlates with the relative error, $\Delta SG * SG^{-1}$, of the specific gravity measurement using the modified air and water method (Fig. 5). This relationship, by assuming $W_A >> \Delta(W_B - W_C)$ and $SG_W = 1$ in equations 1 and 2, simplifies to the expression:

$$\Delta SG * SG^{-1} = \Delta SG_W + \Delta(W_B - W_C) * W_A^{-1} \qquad \text{[Eq. 3]}$$

i.e., heavier corms produce less error in the specific gravity measurement. Corms weighing 0.1 kg have about a $\pm$ 2% error in their specific gravity measurement, while corms weighing over 1 kg have about a $\pm$ 0.3% error.

Commercial processors receive corms with the petiole base attached, since corms deteriorate more rapidly with the petiole base removed. The difference in reporting specific gravity for corms with and without the petiole base may be of minor importance (Fig. 6). Removing the petiole base increases corm specific gravity reporting by less than 3%

During the second year, taro grew under frequent and adequate rainfall at all sites (Table 2 The plants were not subjected to either drought or, because of the porous nature of the soils, flooding. For these reasons, soil water was more or less constant at all sites throughout the production period

Unidentified site-specific factors alter corm specific gravity over time in an unpredictable manner. Similar vagaries in the specific gravity trend were evident for potato tubers when different varieties were harvested over 10-day intervals (Murphy and Goven, 1959). That study did not distinguish between variety and site, leaving open the possibility that changes in tuber specific gravity with harvest age were actually due to site-specific factors and not to variety. Analysis of concentric sections of a corm might reveal layers of varying specific gravity, recording periods of varying starch density accumulation much as tree rings record annual growth.

Within limits, specific gravity may be unaffected by nutrient levels and other factors that influence yield. texture, structure, and other edaphic and climatic factors, however, may play significant roles in influencing specific gravity. The ability to identify, quantify, and manipulate these factors should prove equally beneficial to the fresh corm market and to the fledgling taro processing industry.

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CAPTIONS FOR FIGURES

Fig. 1 **Illustration of a taro plant.** Adapted from Wilson and Hamilton, 1987.

Fig. 2 **Corm specific gravity distributions during the first year.** Vertical scales are specific gravities of corms harvested at 3 sites between April and July, 1989, 6 to 9 months after planting. The distribution for site A, month 7, is omitted because it contained invalid data. Each outlined central box depicts the middle half of the data between the 25th and the 75th percentiles. The dark horizontal line across the box marks the median, and the light horizontal line marks the mean. The whiskers extending from the top and bottom of the box depict the extent of the main body of the data between the 10th and the 90th percentiles, while extreme values are plotted individually with a circle. Each distribution comprises between 17 to 23 observations.

Fig. 3 **Relationship between mean corm specific gravity and the proportion of sand constituting soil texture at 6 sites during the second year.** Each solid circle marks the mean specific gravity of corms harvested 6 months after planting, with error bars denoting the 95% confidence interval. Letters next to the circles identify sites. The empirical curve was produced using the second-order hyperbolic function given in the box.

Fiq 4 **Relationship between corm specific gravity and corm weight.** First and second year observations, including those from site A, month 7, of the first year and from the border rows of the second year, for a total of 441 observations. The curve was produced by a data smoothing procedure that summarizes the middle of the distribution of y for each value of x (Cleveland, 1979).

Fig. 5 **Relationship between the relative error in corm specific gravity measurements and corm weight.** First and second year observations, including those from site A, month 7, of the first year and the border rows of the second year, for a total of 441 observations. The theoretical curve was produced using the hyperbolic function given in the box, equivalent to Equation 3 of the text.

Fig. 6 **Relationship between corm specific gravity with and without the petiole base attached.** Data are from 148 corms harvested from border rows at 6 sites during the second year.

Table 1. Descriptions and test results of soils at the taro production sites during the first year, 1988 to 1989.

Site	Series -- Taxonomic Class
A	Leafu -- very fine, mixed, isohyperthermic, Cumulic Hapludoll
B	Puapua -- medial over cindery, isohyperthermic, Lithic Eutrandept
C	Oloava -- medial over cindery, isohyperthermic, Typic Dystrandept

Site	pH	Percent sand/silt/clay	Textural Class	Org. C (%)	-- mg kg^{-1}-- Ca	Mg	K
A	5.2	16/34/50	clay	2	3800	1780	200
B	6.1	50/28/22	sandy clay loam	5	8600	940	190
C	4.7	36/40/24	loam	8	1400	1240	440

Nakamura, 1984

Table 2. Descriptions and test results of soils at the taro production sites during the second year, 1989 to 1990.

Site	Series -- Taxonomic Class
A	Pavaiai -- medial-skeletal, isohyperthermic, Typic Dystrandept
B	Leafu -- very fine, mixed, isohyperthermic, Cumulic Hapludoll
C	Oloava -- medial over cindery, isohyperthermic, Typic Dystrandept
D	Paupau -- medial over cindery, isohyperthermic, Lithic Eutrandept
E	Sogi -- medial, isohyperthermic, Udic Eutrandept
F	Pavaiai -- medial-skeletal, isohyperthermic, Typic Dystrandept

Site	Rainfall (mm)	pH	Percent sand/silt/clay	Textural Class
A	2108	5.75	25/45/30	clay loam
B	1773	5.52	21/46/33	clay loam
C	1642	6.05	48/37/15	loam
D	1269	6.08	60/29/11	sandy loam
E	1334	6.81	69/26/05	sandy loam
F	1376	6.22	55/35/10	sandy loam

Site	Org. C (%)	N (%)	P (mg kg)	Elec. Conductivity (dS m)
A	2.6	0.19	67	0.12
B	3.1	0.24	56	<0.10
C	5.9	0.26	44	0.10
D	7.2	0.85	48	0.60
E	2.4	0.07	131	<0.10
F	9.7	0.78	37	<0.10

	Percent of Exchange Sites occupied by					
Site	Ca	Mg	K	Na	CEC (cmol kg)	Base Saturation (%)
A	18.3	23.3	2.7	0.5	55	45
B	13.0	24.2	1.2	0.5	64	39
C	8.3	14.8	6.1	0.4	70	30
D	28.4	12.2	5.3	0.6	72	46
E	29.2	21.0	3.0	1.3	45	54
F	11.2	23.0	1.1	0.4	71	36

Nakamura, 1984

Some data missing

Table 3. Analysis of variance sums of squares, including subdivisions for the "month" effect and interaction, for taro corm specific gravity during the first year of the study. Data from site A are omitted. Sums of squares refer to single observations.

Source	df	sums of squares
Site (S)	1	0.082 320***
Month (M)	3	0.012 437**
6 vs 9	1	0.011 620***
7 vs 8	1	0.000 050 NS
6&9 vs 7&8	1	0.000 821 NS
S X M	3	0.007 496*
S X (6 vs 9)	1	0.001 100 NS
S X (7 vs 8)	1	0.001 100 NS
S X (6&9 vs 7&8)	1	0.005 253*
Residual error	112	0.000 788

Significant at the 0.05, 0.01, and 0.001 probability levels, respectively; NS = not significant.

Table 4. Analysis of variance sums of squares, including subdivision for the "site" main effect and interaction, for taro corm specific gravity during the first year of the study. Data from month 7 are omitted. Sums of squares refer to single observations.

Source	df	sums of squares
Site (S)	2	0.098 023***
B vs C	1	0.079 210***
A vs (B & C)	1	0.017 763***
Month (M)	2	0.001 495 NS
S X M	4	0.018 257***
[A vs (B & C)] X (9 vs 6&8)	1	0.011 760***
[A vs (B & C)] X (6 vs 8)	1	0.003 920 NS
(B vs C) X (9 vs 6&8)	1	0.002 420 NS
(B vs C) X (6 vs 8)	1	0.000 327 NS
Residual error	126	0.000 719

*** Significant at the 0.001 probability level; NS = not significant at P = 0.05.

Fig. 1

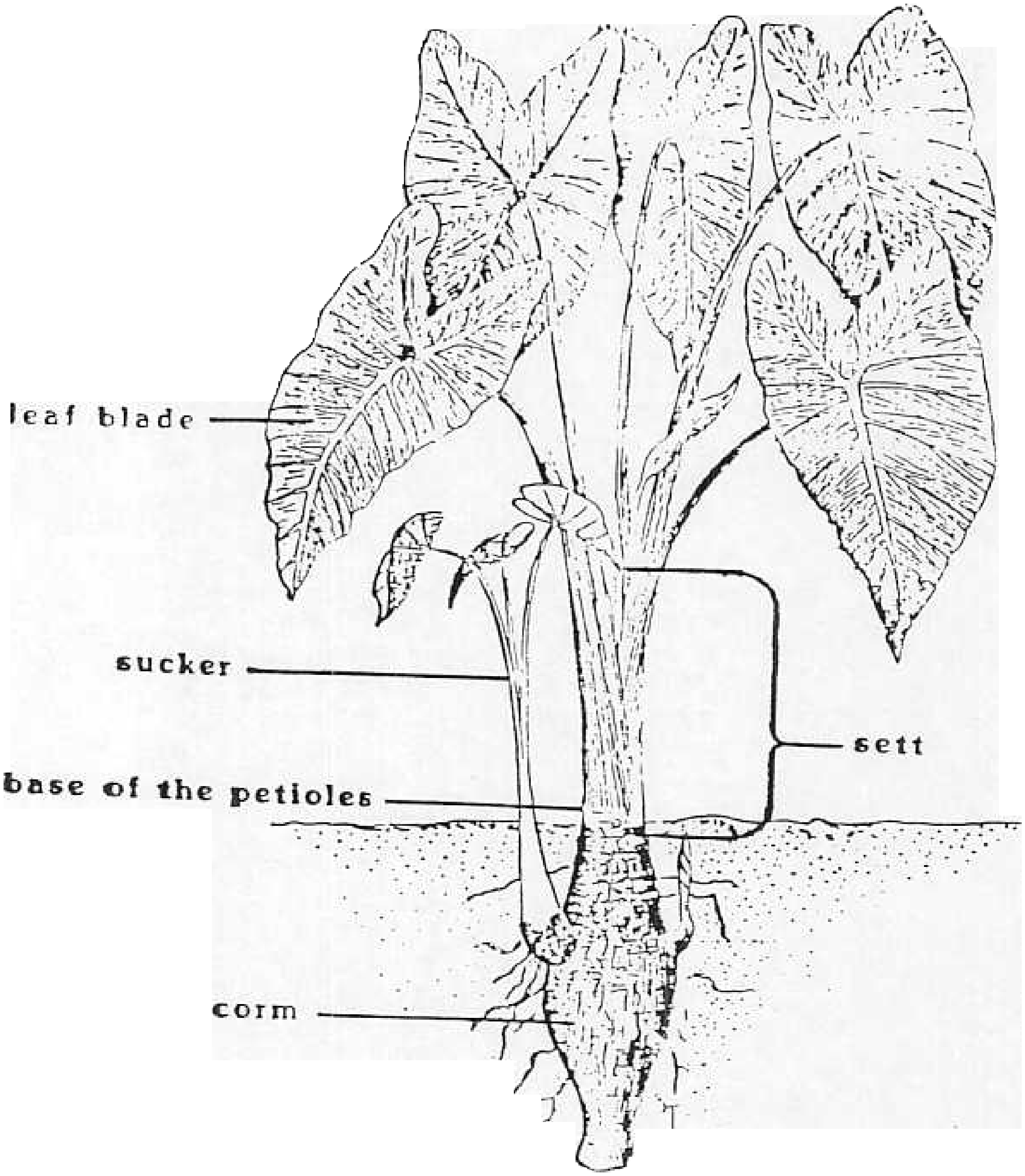
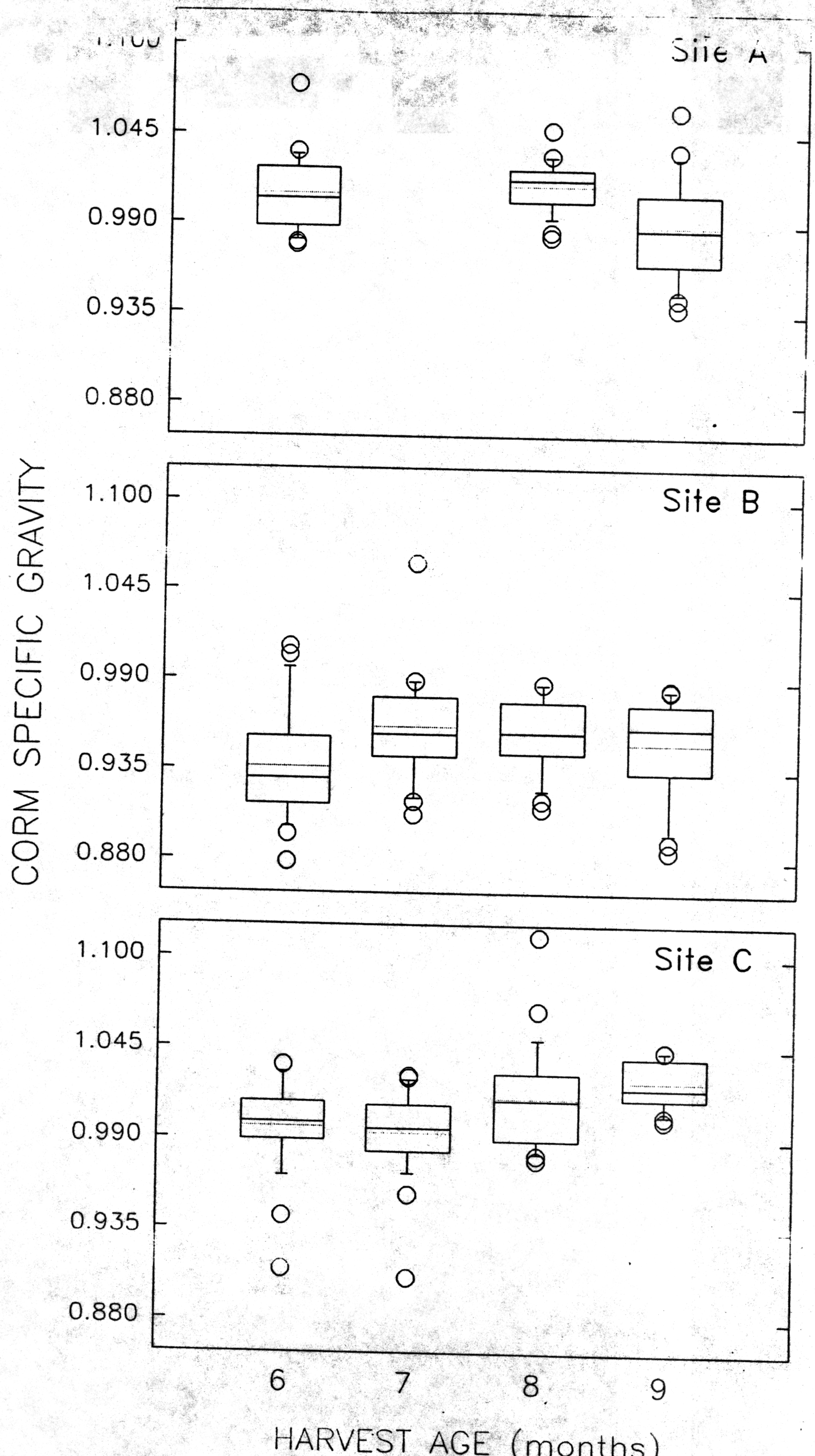
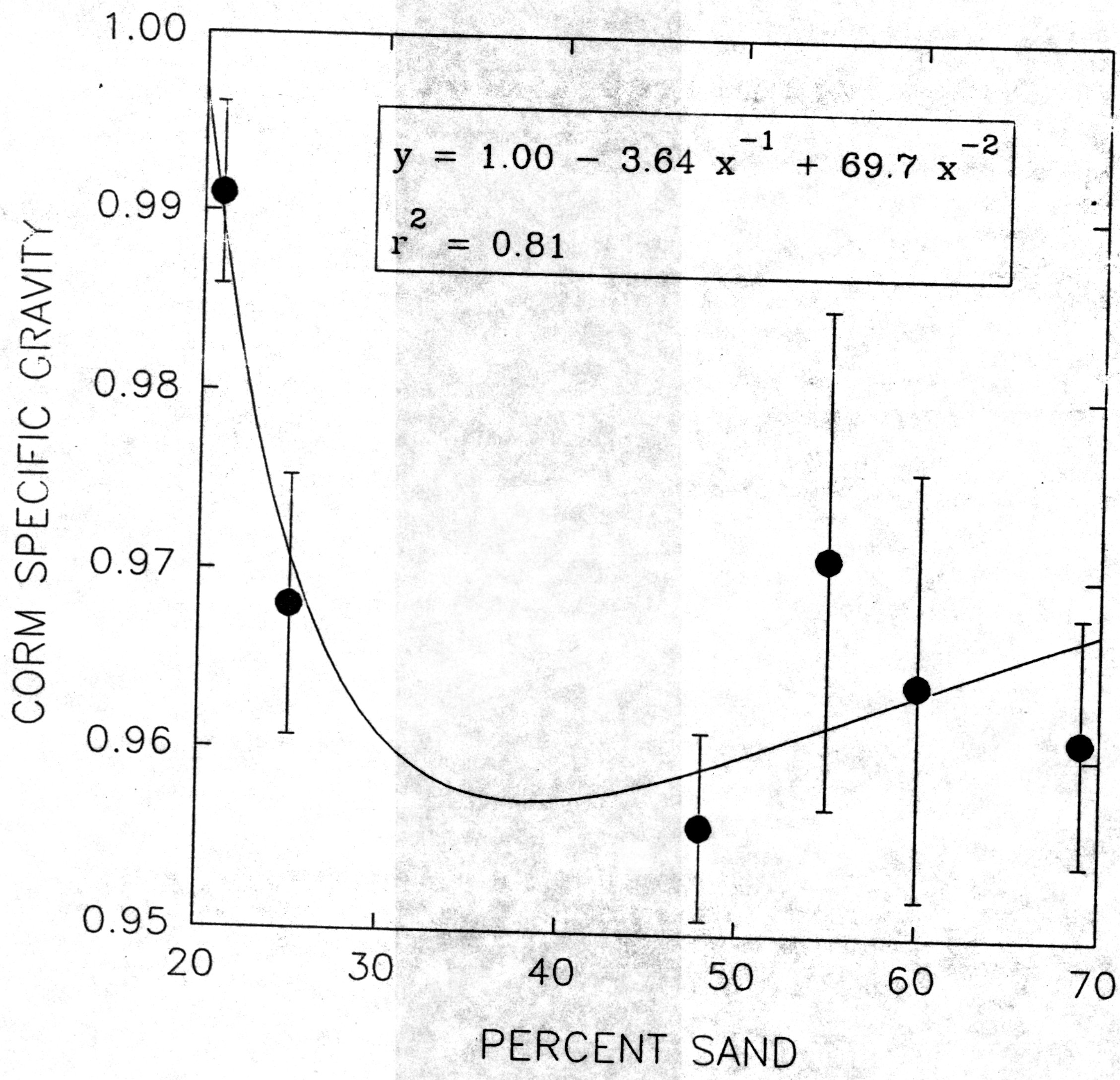


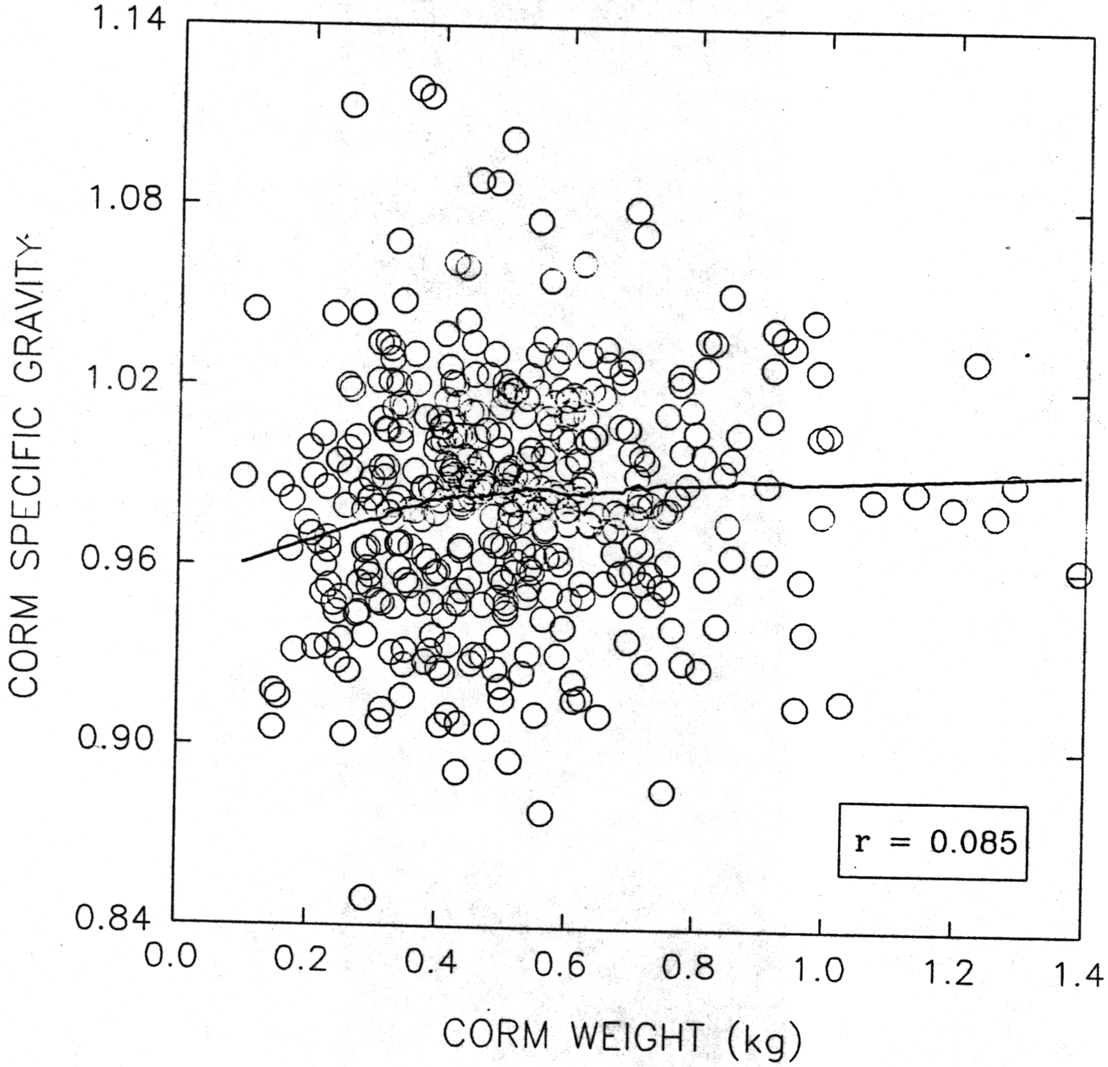
Fig. 2


Site A
Site B
Site C
1.100
1.045
0.990
0.935
0.880
CORM SPECIFIC GRAVITY
6
7
8
9
HARVEST AGE (months)

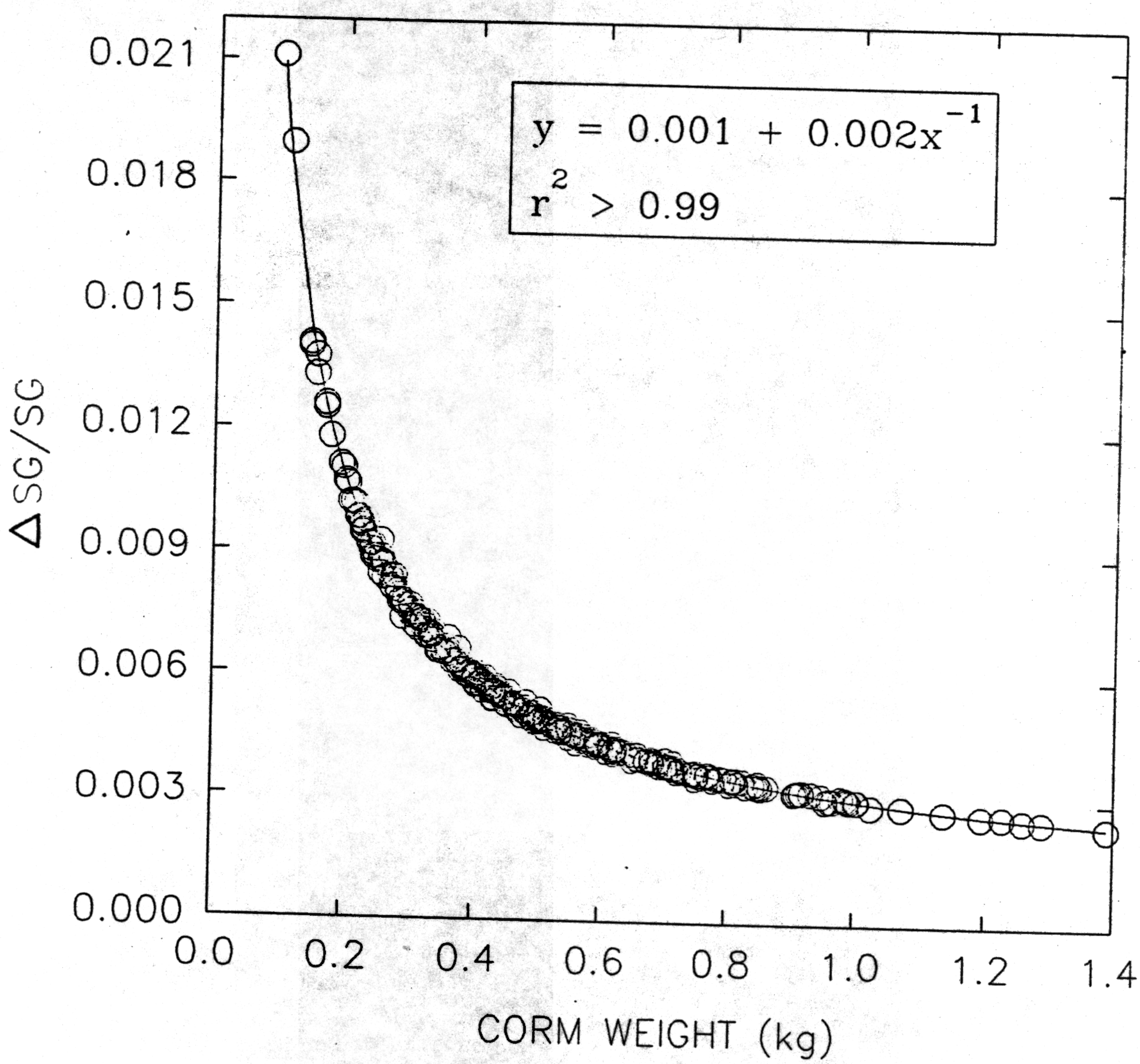


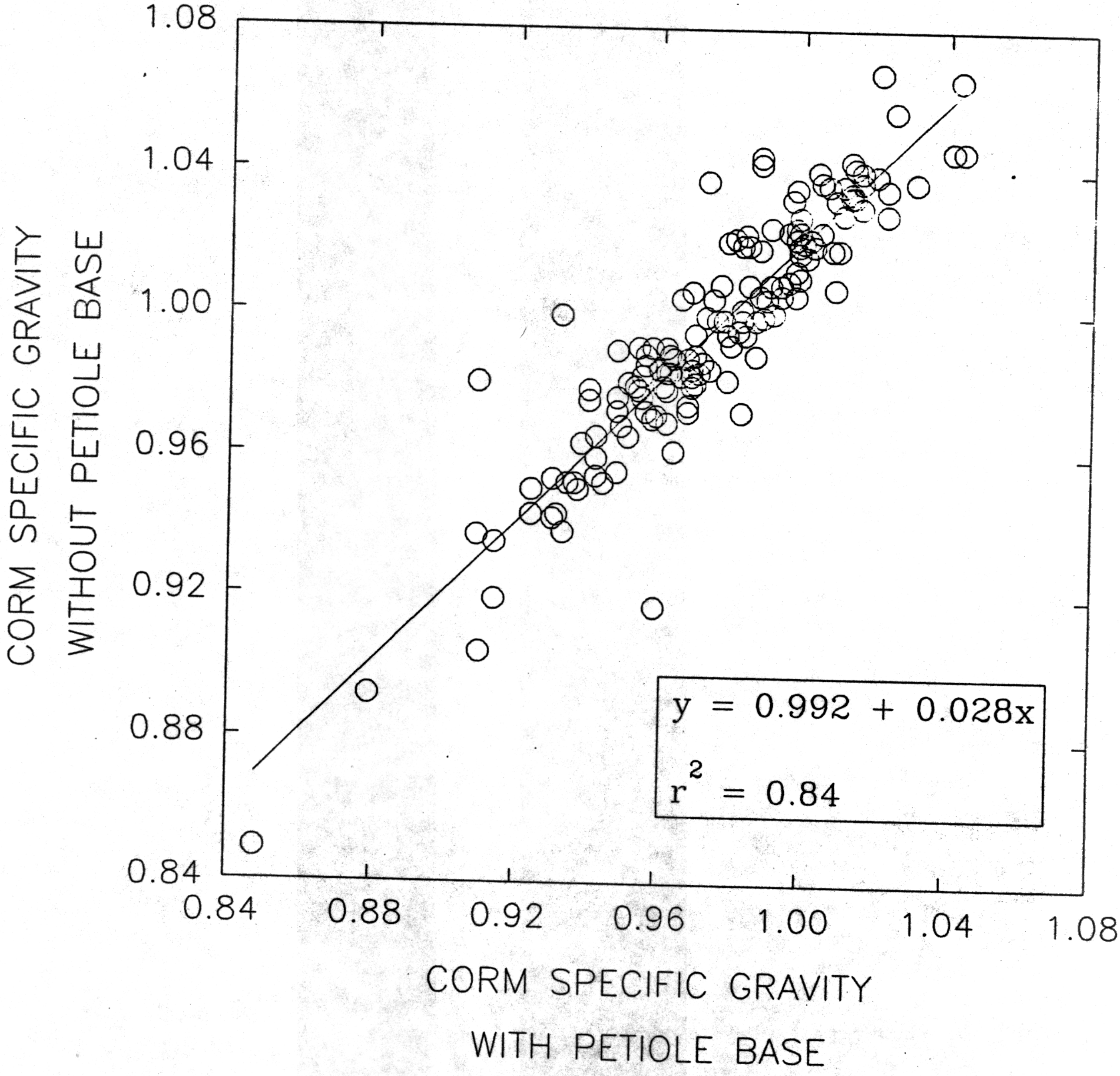
y = 1.00 − 3.64 x^-1 + 69.7 x^-2
r^2 = 0.81
CORM SPECIFIC GRAVITY
1.00
0.99
0.98
0.97
0.96
0.95
20
30
40
50
60
70
PERCENT SAND

Fig. 4



1.14
1.08
1.02
0.96
0.90
0.84
CORM SPECIFIC GRAVITY
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
CORM WEIGHT (kg)
r = 0.085


y = 0.001 + 0.002x^-1
r^2 > 0.99
ΔSG/SG
0.021
0.018
0.015
0.012
0.009
0.006
0.003
0.000
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
CORM WEIGHT (kg)



1.08
1.04
1.00
0.96
0.92
0.88
0.84
CORM SPECIFIC GRAVITY
WITHOUT PETIOLE BASE
y = 0.992 + 0.028x
r2 = 0.84
0.84
0.88
0.92
0.96
1.00
1.04
1.08
CORM SPECIFIC GRAVITY
WITH PETIOLE BASE