Sustainability in terms of nutrient elements with special reference to West-Africa

N. van Duivenbooden

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- achieve optimal and sustainable plant production systems;
- find new agricultural products and improve product quality;
- enhance nature and environmental quality in the countryside.

Address:
CABO-DLO
P.O. Box 14
6700 AA Wageningen
The Netherlands

tel. 31.8370.75700
fax. 31.8370.23110
e-mail postkamer@cabo.agro.nl

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PREFACE

This report has partly been written in the framework of the 'Mopti project', officially designated 'Development of a land use plan for the 5th region of Mali (Region Mopti + Cercle de Niafunké)', a joint activity of the DLO-Centre for Agrobiological Research (CABO-DLO, Wageningen, the Netherlands) and a multidisciplinary team based in Mali (ESPR, Equipe chargée de l'étude sur les Systèmes de Production Rurales en 5ème Région). Although the project was jointly financed by the Directorate-General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs and the Government of Mali (in the framework of the second 5-year plan for the 5th region, financed by the World Bank), the work presented in htis report has been paid by the Ministry of Agriculture, Nature Conservation and Fishery. The other part has been written during my stay as visiting scientist at CABO-DLO.

The aim of the project was to assess the possibilities for regional agricultural development, based on a quantitative description of agricultural production activities (arable crops, livestock and fisheries), both those currently practiced and those potentially feasible from a technical point of view. The project resulted in suggestions for technically feasible development options for sustainable agricultural land use of Mali's Fifth Region. Within the project, a linear programming model was used that combined information on possible activities in the region with information on the regional resources.

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PART A.
ANALYSES, METHOD AND APPLICATION

1. INTRODUCTION

Degradation of natural resources is one of the great problems in many parts of the world, e.g. in sub-Saharan Africa (van Keulen & Breman, 1990; Stoorvogel & Smaling, 1990). Evidently, degradation of the natural resource base can take many different forms. Of particular importance in sub-Saharan Africa are chemical exhaustion of soils, disappearance of perennial grasses from the flood plains, mortality of shrubs and trees on the rangelands, surface crusting and sealing on loamy soils and wind erosion. This degradation leads to a lower production capacity of the land. Hence, this may jeopardize the self-sufficiency in food of certain areas within a country or of the country as a whole. Due to the increasing population it becomes increasingly difficult to produce sufficient food, so that higher food imports are required. Action should thus be taken to prevent a further decline in quality and quantity of natural resources.

This concern about the state of the natural resources has in recent years been expressed by emphasizing 'sustainability'. Its definition and implications have been discussed in many papers and books (Budelman & van der Pol, 1992; Meerman *et al.*, 1992; Vereijken, 1992; FAO, 1991a; de Ridder & van Keulen, 1990; Vlek, 1990). However, these definitions are generally expressed in 'elusive terms', i.e. they are difficult to quantify. The operational definition applied in this report has been derived from the definitions given by the Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR): 'the successful management of resources for agriculture to satisfy changing human needs, without degrading the environment or the natural resource base on which agriculture depends' (TAC, 1989). For operational purposes, sustainability has been defined in terms of nutrients in arable cropping systems, i.e. the soil nutrient balances of the macroelements N, P and K in the rootable layer of the soil are maintained in equilibrium in the long run, through nutrient application that guarantees a sufficient nutrient uptake to allow realization of pre-defined target yields.

This criterion of equilibrium in the nutrient balance, with respect to macronutrients (i.e. nitrogen: N, phosphorus: P and potassium: K) was selected for two reasons. Firstly, in semiarid regions nitrogen and phosphorus availability limit growth more often than moisture availability (Seligman *et al.*, 1992; Piéri, 1989; Penning de Vries & Djitèye, 1982). Secondly, in many developed countries overuse and waste of nutrients threatens sustainability, which becomes clear through environmental pollution. Nitrogen is a component of many important organic compounds ranging from proteins to nucleic acids; phosphorus plays a major role in energy transfer and protein metabolism and potassium is important for osmotic and ionic regulation and functions as a cofactor or activator for many enzymes of carbohydrate and protein metabolism (e.g. Baligar *et al.*, 1990).

If the soil can not supply sufficient plant nutrients to satisfy crop demand, the yield level is determined by the amount of the limiting nutrient that can be taken up. This constraint can be removed by appropriate fertilizer application. This results in increasing yields with increasing nutrient availability, until another growth factor (e.g. water, radiation) becomes limiting. Hence, for definition of sustainable cropping systems, supply of nutrient from natural sources ('natural soil fertility'), fertilizer effects and nutrient cycles play a key-role.

For such an analysis, a modeling approach can be used. In the last decade, various models dealing with nutrient cycles in the soil-plant system have been developed (e.g. Groot & van Keulen, 1990; Janssen *et al.*, 1987; van Keulen & Seligman, 1987; van Noordwijk *et al.*, 1990; Wolf & van Keulen, 1989; Wolf *et al.*, 1987; 1989), but some are complex and require much detailed information, which is generally not available in developing countries. In addition, these models do not calculate the external nutrient requirements to maintain a sustainable production system at the desired target yield level.

In this study, a simple straightforward calculation procedure has been developed to allow quantification of inputs and outputs of sustainable cropping systems. Secondly, the impact of sustainability in terms of nutrients on regional agricultural development is established.

For validating this method NUREQ (Chapter 3), fertilizer experiments have been analysed (Chapter 2). The method has been used to examine the possibilities for agricultural development in relation to food needs in the Fifth Region of Mali (Chapter 4).

Part B (Chapters 5 to 14) deals with detailed crop parameters, such as biomass distribution among principal plant organs and nutrient uptake relations.

Crops treated in this report are millet (*Pennisetum americanum*), sorghum (*Sorghum bicolor*), maize (*Zea mays*), rice (*Oryza sativa*), wheat (*Triticum aestivum*), fonio (*Digitaria exilis*), groundnut (*Arachis hypogaea*), cowpea (*Vigna unguiculata*), bambara groundnut (*Vigna subterranea*) and cotton (*Gossypium spp*).

2. FERTILIZER APPLICATION ANALYSIS

2.1 Methodology

For a quantitative description of nutrient balances in different cropping systems, insight is necessary in the dynamic behaviour of nutrients. Such information is very often lacking in fertilizer experiments, where only crop response in terms of yield has been determined, and nutrient content has not been measured. That variable is very important as it provides information about two relations: *(i)* the fraction of the nutrient applied effectively taken up (recovery fraction) and *(ii)* the increase in yield per unit additional nutrient uptake.

Lack of response to fertilizer application may be due to the fact that the nutrient has not been taken up, because it was applied at the wrong time, in the wrong place or in the wrong form, or that higher content was not expressed in increased economic yield. The latter may be due to other growth-limiting factors, such as shortage of water or mineral elements, other than the one applied. However, the common way of presenting yield as a function of fertilizer applied makes it impossible to distinguish between these two reasons for lack of response (van Keulen, 1982). Hence, to evaluate the value of the recovery fraction and the slope of the nutrient content-yield curve, fertilizer experiments are best analysed by means of three quadrant figures. Such a figure (Figure 2.1) consists of the following relations:

- Quadrant A shows the relation between nutrient content at maturity (E_u) and crop yield (Y). The yield increase per unit additional nutrient uptake depends on crop species, level of nutrient content and conditions with respect to other growth factors;
- Quadrant B shows the relation between the amount of a nutrient applied (E_a) and nutrient content (E_u). This reflects losses by leaching, volatilization, etc.;
  Supply from natural resources ('natural soil fertility'), defined as nutrient availability in the absence of fertilizer or manure application including processes of weathering, equals thus the intercept with the X-axis;
  The recovery fraction at a certain application rate is defined as the uptake at that rate minus the uptake at zero application, divided by the application rate. It depends on fertilizer type, time and method of application and environmental conditions;
- Quadrant C, constructed from the other two by elimination of the content, shows the classical response curve: the relation between the amount of a nutrient applied (E_a) and crop yield (Y).

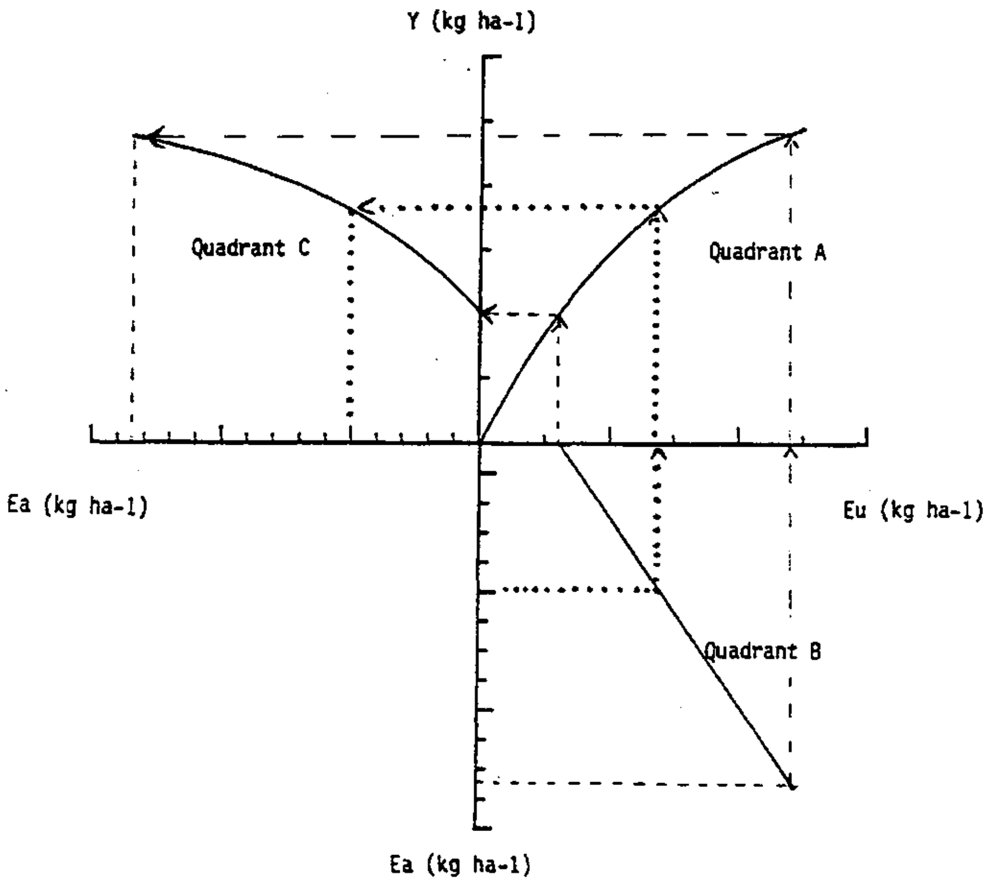


Figure 2.1. *General graphical presentation of the relation between total nutrient content (E_u) and yield (Y) (Quadrant A), that between nutrient application (E_a) and nutrient content (Quadrant B), and that between nutrient application and yield (Quadrant C).*

To ensure that the data refer more or less to the agro-ecological domain of the species, only field experiments were considered and (except for rice) little attention was given to experimental results under irrigated conditions. Data were obtained from literature, either directly from tables or derived from graphs or histograms. From these basic data the following characteristics were derived: nutrient content in the course of the growing season (Section 2.2); harvest index (Subsection 2.3.1), minimum and average nutrient concentrations (Subsection 2.3.2), nutrient harvest indices (Subsection 2.3.3), nutrient content in relation to biomass production (Section 2.4), nutrient content related to nitrogen content (Section 2.5) and the recovery fraction (Section 2.6). (N, P and K have been expressed throughout the report in elementary form; conversions used are: $P = P_2O_5/2.29$ and $K = K_2O/1.205$).

As a detailed discussion of individual data is not feasible in this review, lumped data have been analyzed, despite interspecies and intraspecies differences in experimental conditions (soil, weather and fertilizer treatment) and genetics which may cause considerable variation. Results were analyzed with the statistical language Genstat (Payne *et al.*, 1988). Homologous means were compared with Wilcoxon's rank sum test (two-sided, p = 0.05; Hollander & Wolfe, 1973). The relation of two variables within a crop has been investigated as follows. Firstly, the correlation coefficient was calculated. If that differed significantly from zero (two-sided, $p = 0.05$; cf. Fisher & Yates, 1963) the line with minimum sum of squared distances was determined for use in graphs. This line was preferred above either of the two possible ordinary regression lines because both variables are random. Homologous correlation coefficients have been compared between the five species with the Fisher's z-method (Anderson, 1958).

It should be noted that the way in which the data have been collected does not enable a statistical *proof* of the existence of a relationship within a crop or of some difference among the species. Moreover, environmental conditions for the five species are *perse* different. The statistical procedures only check whether a seeming effect might have been caused by a selected simple change mechanism (no spurious relation) rather than by an actual effect. Observed relations within a crop indicates that the underlying mechanism acts indifferent of environmental conditions.

2.2 Nutrient content in the course of the growing season

Nutrient uptake by the crop is affected by many factors, which makes it difficult to predict the response to fertilizer application. These factors include:

1. Prevailing weather conditions (rainfall, temperature): drought reduce N-uptake and biomass production (Pichot *et al.*, 1974, Figure 5.3cd);
2. Soil type, e.g. acid soils show a lower phosphorus recovery fraction than other soil types (e.g. Fox *et al.*, 1974);
3. Crop characteristics: differences in length of growing season, root characteristics, sink size (grains) and other differences between varieties (e.g. Singh & Thakare, 1986, Figure 5.3h);
4. Type of fertilizer applied, differences exist between e.g. urea and ammonium-type fertilizers (e.g. Verma *et al.*, 1972, Figure 7.2e; Blondel, 1971b, Figure 8.2b);
5. Timing of fertilizer application, as e.g. a longer residence time of fertilizer in the soil (e.g. basic dressing) increases the risks of losses; secondly, after a certain phenological stage of the crop additional uptake becomes negligible (e.g. Below & Gentry, 1992; Russelle *et al.*, 1983; Reddy & Patrick, 1976). Split application (including one at anthesis) increases uptake (Kropff *et al.*, 1992).
6. Application method, for instance for rice by deep placement of N-fertilizer (Singh & Singh, 1987a,b; Reddy & Patrick, 1976);
7. Availability of other macronutrients, with P-application N-uptake increased (e.g. Perry & Olson, 1975; Mahapatra & Pande, 1972; Rai, 1965a,b, Figure 6.3d) and with N-application P-uptakes increased (Roy & Wright, 1973, 1974, Figure 6.4c);
8. History of the field: after fallow a lower uptake is observed than after a fertilized crop due to absence of residual effects (e.g. Adepetu & Corey, 1977);
9. Presence and method of irrigation (e.g. Wright *et al.*, 1985);
10. Cultural practices, such as presence of Azolla in rice fields (Singh & Singh, 1987a,b), intercropping with leguminous species (e.g. Ofori & Stern, 1987), weeding (Kang *et al.*, 1977, Figure 7.2a), etc.

2.2.1 Relative post-anthesis nutrient uptake

Nutrient uptake during the post-anthesis period is, in addition to the above, affected by other factors. For nitrogen these include:

1. The presence of green leaf blades and soil water (e.g. Ellen & Spiertz, 1975);
2. Genetic differences between species (under the same conditions) and between varieties (e.g. Tsai *et al.*, 1991; Muchow, 1988; Cox *et al.*, 1985; Pollmer *et al.*, 1979; Woodruff, 1972);
3. Post-anthesis root growth. Post-anthesis root growth, in terms of both dry weight and rooting depth, has been reported for millet (Chopart, 1983), and for maize, although varietal differences existed (Anderson, 1988; Barber & Mackay, 1986; Mengel & Barber, 1974a,b).
4. Soil N-availability: in certain cases nitrogen have to be applied before an increase of post-anthesis N-uptake can be observed (e.g. Cassman *et al.*, 1992; Youngquist & Maranville, 1992; Basinski & Airey, 1970); any process that yields N-losses (especially if residence time of fertilizer is long) reduces the possibility for post-anthesis N-uptake. As it is beyond the scope of this article to go into the soil processes in detail, reference is made to e.g. Baligar & Bennett (1986).
5. Timing of N-application: application at ear initiation or anthesis promotes post-anthesis uptake (e.g. Cassman *et al.*, 1992; Singh & Randhawa, 1979; Ellen & Spiertz, 1975; Eilrich & Hageman, 1973);
6. Climatological conditions, which affect growth and senescence of the crop, mineralisation processes in the soil, etc., (e.g. Tsai *et al.*, 1991; Anderson *et al.*, 1985; Sharma & Prasad, 1980; Khalifa *et al.*, 1977; Woodruff, 1972; Rai, 1965b). Gigou (1984) also observed post-anthesis N-uptake after a drought period. This is explained by continued mineralisation from soil organic matter, which allows post-anthesis N-uptake after resumption of the rains;

For phosphorus and potassium, the same factors explain the observed variability. For potassium, additional soil characteristics have strong effects, i.e. the content of Ca and Mg (De Datta, 1985), due to the exchange possibilities among these three nutrients in plant physiological processes (de Wit *et al.*, 1963).

If the post-anthesis nutrient uptake is zero, that does not necessarily imply absence of uptake, but may also indicate that losses (Subsection 2.2.2) are compensated by uptake.

Relative post-anthesis nutrient uptake is defined as the increase in nutrient content after anthesis as a fraction of maximum nutrient content. For nitrogen, phosphorus and potassium, it is referred to as RNU (Relative post-anthesis Nitrogen Uptake), RPU and RKU, respectively. Reliable results can only be obtained, if regular crop harvests and accompanying chemical analyses have been carried out. However, as such data are scarce, experiments for which at least nutrient content in the crop at flowering and at maturity were reported, have been included.

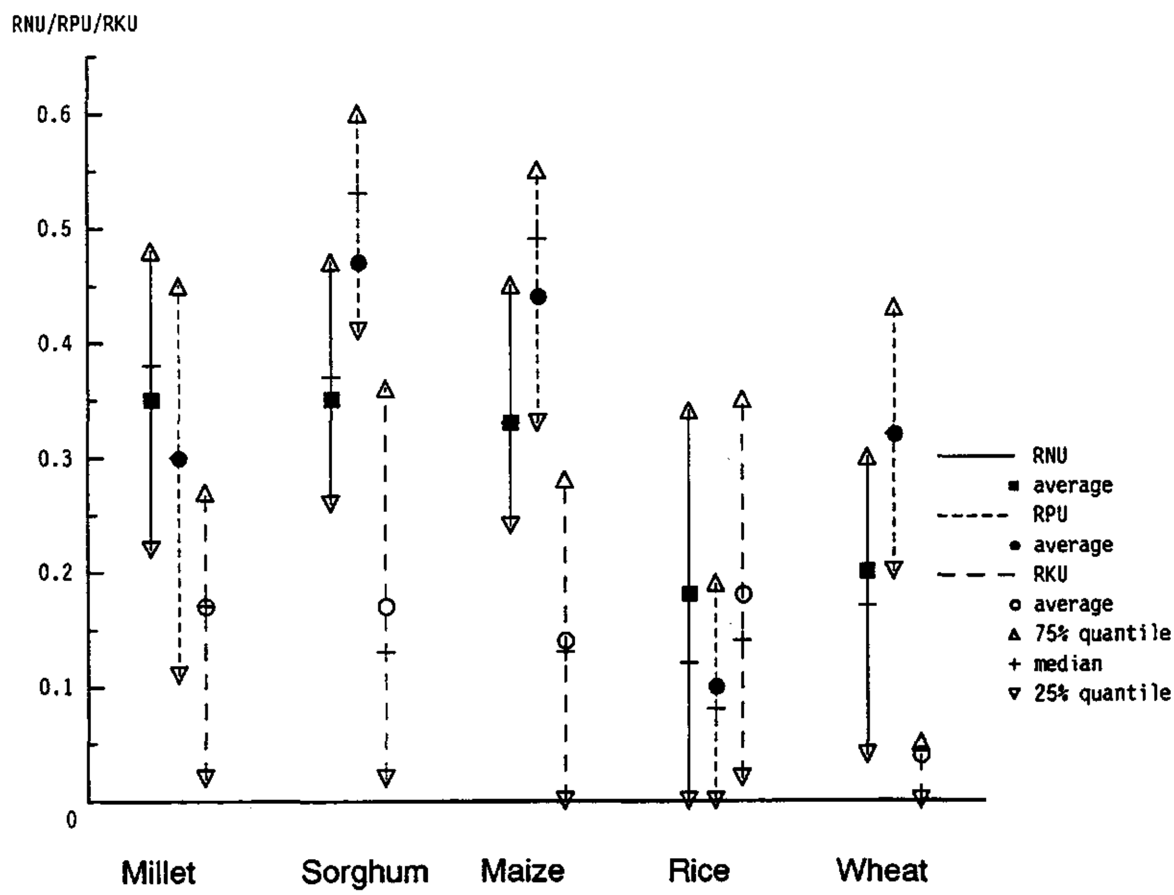


Figure 2.2. *Characteristics of the frequency distribution of the relative post-anthesis nitrogen, phosphorus and potassium uptake (RNU, RPU, RKU) in relation to the average value in millet, sorghum, maize, rice and wheat.*

Sources: Millet: Blondel, 1971a,c; Cissé, 1988; Coaldrake & Pearson, 1985; van Duivenbooden & Cissé, 1989; Ganry, 1990; Gosseye, unpublished; Gregory 1979; Kassam & Stockinger, 1973; Munda et al., 1984; Payne, 1990; Rodriquez et al., 1990; Siband, 1981; Singh & Randhawa, 1979;

Sorghum: Arrivets, 1976; Babu & Singh, 1984b; Bennett et al., 1990; Blondel, 1971a; Duncan & Baligar, 1990; Gigou, 1981, 1984; Govil & Prasad, 1974; Jacquinot, 1964; Kassam & Stockinger, 1973; Lafitte & Loomis, 1988; Locke & Hons, 1988; Maranville et al., 1980; Myers, 1978b; Muchow, 1988, 1990; Rai, 1965b; Roy & Wright, 1974; Singh & Bains, 1973; Turkhede & Prasad, 1980;

Maize: Allison, 1984; Anderson et al., 1984a, 1985; Bacon & Thompson, 1984; Bakema, 1981; Beauchamp et al., 1976; Bigeriego et al., 1979; Blondel, 1971a; Bromfield, 1969; di Fonzo et al., 1982; Gigou & Chabalier, 1987; Grimme, 1985; Hanway, 1962; Hay et al., 1953; Jordan et al., 1950; Karlen et al., 1987, 1988; Loué, 1963; Lubet & Juste, 1985; Mackay & Barber, 1986; Mehla & Singh, 1980; Mengel, 1979; Mengel & Barber, 1974b; Moll et al., 1982; Moustafa & Sheif-El-Yazal, 1980; Muchow, 1988; Peck & MacDonald, 1975; Rai, 1965b; Roads & Stanley, 1981; Sayre, 1948; Schröder, 1989; Slaats & Ukkerman, 1983; Thom & Watkin, 1978; Tsai et al., 1991; Versteegh, 1985; Welch & Flannery, 1985;

Rice: Agarwal, 1980; Basinski & Airey, 1970; Blondel, 1971a,b; De Datta, 1981; 1985; De Datta & Mikkelsen, 1985; De-Yin & Bao, 1985; Fageria et al., 1982; Gigou & Chabalier, 1987; Grimme, 1985; Gupta & O'Toole, 1986; Humphreys et al., 1987; Koyama & Chammek, 1971; Makarim et al., 1991; Samantaray et al., 1990; Schnier et al., 1990; Sims & Place, 1968; Singh & Modgal, 1979; Tanaka et al., 1959; (available but could not be included due to time restrictions: Kropff et al., 1992 (0.26, 0.0, 0.11));

Wheat: Boatwright & Haas, 1961; Cassman et al., 1992; Cox et al., 1985; DeTurk, 1942; Echeverria et al., 1992; Eilrich & Hageman, 1973; Ellen & Spiertz, 1975, 1980; Gasser & Thornburn, 1972; Gregory et al., 1979, 1981; Grimme, 1985; Groot, 1987; Johnston & Fowler, 1991; van Keulen & Seligman, 1987; Khalifa et al., 1977; Knowles & Watkin, 1931; Lal et al., 1978; Maschhaupt, 1922; McNeal et al., 1966; Mengel, 1979; Mikesell & Paulsen, 1971; Mohamed & Marshall, 1979; Paccaud et al., 1985, Page et al., 1977; Papakosta & Gagianas, 1991; Racz et al., 1965; Remy, 1933; Sharma & Prasad, 1980; Singh, 1962; Spiertz & Ellen, 1978; Spiertz & de Vos, 1983; Stapper & Fischer, 1990; Thorne et al., 1988; Venugopalan & Prasad, 1989; Waldren & Flowerday, 1979.

Uptake of macro-nutrients during the post-anthesis period takes place in all cereals considered. The relative value, however, varies considerably among species for each nutrient (Figure 2.2). The relative post-anthesis phosphorus uptake exceeds that of nitrogen, except in millet and rice, and the relative post-anthesis potassium uptake is lowest of the three, except in rice.

Average relative post-anthesis nitrogen uptake (RNU) differs significantly among millet, sorghum and maize (0.33-0.35) on the one hand and rice and wheat (0.18-0.20) on the other, but values are not significantly different within each group (Table 2.1).

For phosphorus, such a distinction in groups can not be made. The relative post-anthesis phosphorus uptake (RPU) in sorghum and maize (0.44-0.47), is significantly higher than in the other species, while in millet and wheat (about 0.31) it is significantly higher than in rice (0.10, Table 2.1).

It appears that post-anthesis P-uptake is not correlated to that of nitrogen, except in sorghum and wheat, where a strong correlation exists (Figures 6.10a and 9.10a, respectively). For the other cereals this correlation is weaker (for millet, maize and rice, Figures 5.11a, 7.10a and 8.11a, respectively).

Table 2.1. *Average value and standard error (s.e.) of relative post-anthesis nitrogen (RNU), phosphorus (RPU) and potassium (RKU) uptake for five major cereals (n = number of observations). Different letters (^{a,b,c}) denotes a significant difference at 95% probability for each characteristic.*

	Millet	Sorghum	Maize	Rice	Wheat
RNU					
average	0.35^a	0.35^a	0.33^a	0.18^b	0.20^b
s.e.	0.19	0.16	0.15	0.17	0.17
(n)	(59)	(96)	(144)	(89)	(221)
RPU					
average	0.30^a	0.47^b	0.44^b	0.10^c	0.32^a
s.e.	0.21	0.17	0.19	0.10	0.18
(n)	(45)	(40)	(46)	(34)	(52)
RKU					
average	0.17^a	0.17^a	0.14^a	0.18^a	0.04^b
s.e.	0.13	0.16	0.14	0.17	0.07
(n)	(15)	(14)	(49)	(60)	(29)

Relative post-anthesis potassium uptake (RKU) does not differ significantly among millet, sorghum, maize and rice (i.e. 0.14 - 0.18), but the value for wheat is significantly lower (0.04, Table 2.1).

RKU is not correlated to RNU nor to RPU, except in sorghum, where a strong correlation is observed (Figure 6.10a and 6.10b), suggesting a linkage between N and K, and P and K uptake processes in the post-anthesis period. For the other cereals, the absence of those relations suggests that during grain filling potassium is not the only active carrier for nitrogen and phosphorus. It is likely that other cations, such as Ca and

Mg may, to a varying degree, perform that function. It has been observed that when RKU ceased, the post-anthesis uptake of Mg and Ca continued (Barraclough, 1986; Bakema, 1981; Arrivets, 1976; Gasser & Thornburn, 1972, Jacquinot, 1964). Another proof that uptakes of K, Mg and Ca are correlated is presented by the linear relationship between K+Mg+Ca content and total aboveground dry matter, whereas for each of the nutrients separately, such a correlation did not exist (van Duivenbooden & Cissé, 1992; see also Figures 5.9, 6.8, 7.8, 8.8 and 9.8).

2.2.2 Nutrient content at maturity in relation to maximum content

The ratio of nutrient content at maturity to maximum nutrient content has been derived from data sets having at least one additional observation on nutrient content between flowering and maturity. From the cumulative frequency distribution the fraction of data of which the nutrient content at maturity was equal to the maximum nutrient content was derived and for the remainder the range in losses was established.

If nutrient content at maturity is lower than the maximum content, the difference is called 'loss', referring to aboveground dry matter. It does not necessarily mean loss from the production system.

Possible causes for nitrogen losses are: *(i)* falling leaf blades, *(ii)* transport to the atmosphere in gaseous form, mainly as NH_3, but also as N_2 and NO_x, the magnitude of these losses being related to e.g. leaf temperature, leaf N-concentration and transpiration rate (Farquhar *et al.*, 1983), *(iii)* leaching by rain (Gigou, 1984) and *(iv)* translocation to the roots (resulting in a small increase in N-concentration as observed in sorghum; Arrivets, 1976). The magnitude of the losses has been related to N-concentration at anthesis in wheat (Papakosta & Gagianas, 1991), but this has not been confirmed for other species or in other experiments with wheat.

Possible causes of P-losses are leaf fall (Gigou, 1984) and translocation to the roots (leading to a sharp increase in P-concentration, as observed in sorghum; Arrivets, 1976).

Possible causes for K-losses are *(i)* leaf fall, *(ii)* translocation to roots and stubble (and eventually to the soil), as a consequence of its function as carrier (e.g. De Datta & Mikkelsen, 1985; Demolon quoted by Gigou, 1984; Mengel, 1979; Sayre, 1948) and *(iii)* leaching by rain (Schenk & Feller, 1990; De Datta & Mikkelsen, 1985; Cooke quoted by Gigou, 1984; Mengel, 1979).

Unfortunately, the relative contribution of the various processes could not be quantified for either of the three nutrients. Observations between flowering and maturity are less frequently available than at either those moments. In this respect, maize and wheat are best investigated and rice least. The results of the various characteristics are presented in Table 2.2.

This means in words, for instance for millet, that in 64% of the experiments the N-content at maturity was the maximum N-content, or maturity was the time of maximum content. For the remainder of the experiments, losses were observed, ranging from 2 to 51% of the maximum content.

As these ranges are not convenient for assessment of maximum nutrient content on the basis of nutrient content at maturity, a multiplier is proposed (Table 2.3). The multiplier is calculated as one plus the relative contribution of the median of losses. For instance, the median of N-losses in millet equals 27% and the occurrence of losses is 36%. Hence, the multiplier equals 1 + 0.27*0.36 = 1.10.

Table 2.2. *Median of nutrient content at harvest as fraction of maximum content, percentage of observations where nitrogen, phosphorus and potassium content at final harvest (maturity) equals maximum content (H=M) and for the remainder, the range of losses between maximum content and content at maturity for five major cereals (n = number of observations).*

	Millet	Sorghum	Maize	Rice	Wheat
Nitrogen					
median	-	-	-	98	-
H=M	64	85	84	47	69
range losses	2-51	1-15	2-46	2-46	1-31
(n)	(39)	(68)	(77)	(36)	(88)
Phosphorus					
median	-	-	-	90	-
H=M	72	100	76	50	76
range losses	1-46	-	5-43	10-26	1-37
(n)	(39)	(15)	(45)	(6)	(34)
Potassium					
median	86	90	94	95	65
H=M	12	0	35	50	0
range losses	1-44	6-16	4-51	5-40	10-53
(n)	(17)	(7)	(46)	(14)	(16)

Sources: Millet: Cissé, 1988; van Duivenbooden & Cissé, 1989; Gregory 1979; Munda et al., 1984; Payne, 1990; Rodriquez et al., 1990; Siband, 1981; Singh & Randhawa, 1979;

Sorghum: Babu & Singh, 1984b; Gigou, 1984; Govil & Prasad, 1974; Lafitte & Loomis, 1988; Roy & Wright, 1974; Singh & Bains, 1973;

Maize: Anderson et al., 1984a; Bakema, 1981; Beauchamp et al., 1976; Bigeriego et al., 1979; Blondel, 1971a; Bromfield, 1969; Grimme, 1985; Hanway, 1962; Hay et al., 1953; Jordan et al., 1950; Karlen et al., 1987, 1988; Lubet & Juste, 1985; Mackay & Barber, 1986; Mehla & Singh, 1980; Mengel, 1979; Roads & Stanley, 1981; Sayre, 1948; Thom & Watkin, 1978; Versteegh, 1985;

Rice: Blondel, 1971b; De-Yin & Bao, 1985; Grimme, 1985; Humphreys et al., 1987; Samantaray et al., 1990; Schnier et al., 1990; Sims & Place, 1968;

Wheat: Boatwright & Haas, 1961; DeTurk, 1942; Echeverria et al., 1992; Ellen & Spiertz, 1975, 1980; Gasser & Thornburn, 1972; Gregory et al., 1979, 1981; Grimme, 1985; Groot, 1987; van Keulen & Seligman, 1987; Khalifa et al., 1977; Knowles & Watkin, 1931; Lal et al., 1978; McNeal et al., 1966; Mengel, 1979; Mohamed & Marshall, 1979; Page et al., 1977; Singh, 1962; Spiertz & Ellen, 1978; Spiertz & de Vos, 1983; Waldren & Flowerday, 1979.

Table 2.3. *Proposed multipliers for calculation of maximum nutrient content on the basis of nutrient content at maturity (= 1 + (the median of losses * the fraction of experiments showing losses)).*

Crop	Nitrogen	Phosphorus	Potassium
millet	1.10	1.05	1.02
sorghum	1.01	1.00	1.09
maize	1.03	1.04	1.07
rice	1.06	1.09	1.13
wheat	1.03	1.04	1.35

2.3 Dry matter and nutrient distribution

2.3.1 Dry matter harvest index

Dry matter harvest index (HI, the weight ratio of marketable product (grain) to total aboveground dry matter) is used as discriminator since dry matter distribution also plays a role in the distribution of nutrients and provides information on the potential use of the crop (food, fodder, or a combination of the two). Its value is determined by genetic factors and environmental conditions (Powell & Hons, 1992; Donald & Hamblin, 1976).

Probability curves have been constructed for millet, sorghum, maize, rice and wheat, under West-African and other conditions separately (Figures 5.2, 6.2, 7.1, 8.1 and 9.1, respectively). The 50% level for millet, sorghum, maize and irrigated wheat under West African conditions is 0.22, 0.20, 0.41, and 0,45, respectively, compared to 0.28, 0.31, 0.44 and 0.41, respectively in experiments from other parts of the world. HI of rice equals 0.43 in both conditions.

Figure 2.3 shows the main characteristics of the frequency distribution for combined observations in five cereals. The average values in experiments are given in Table 2.4.

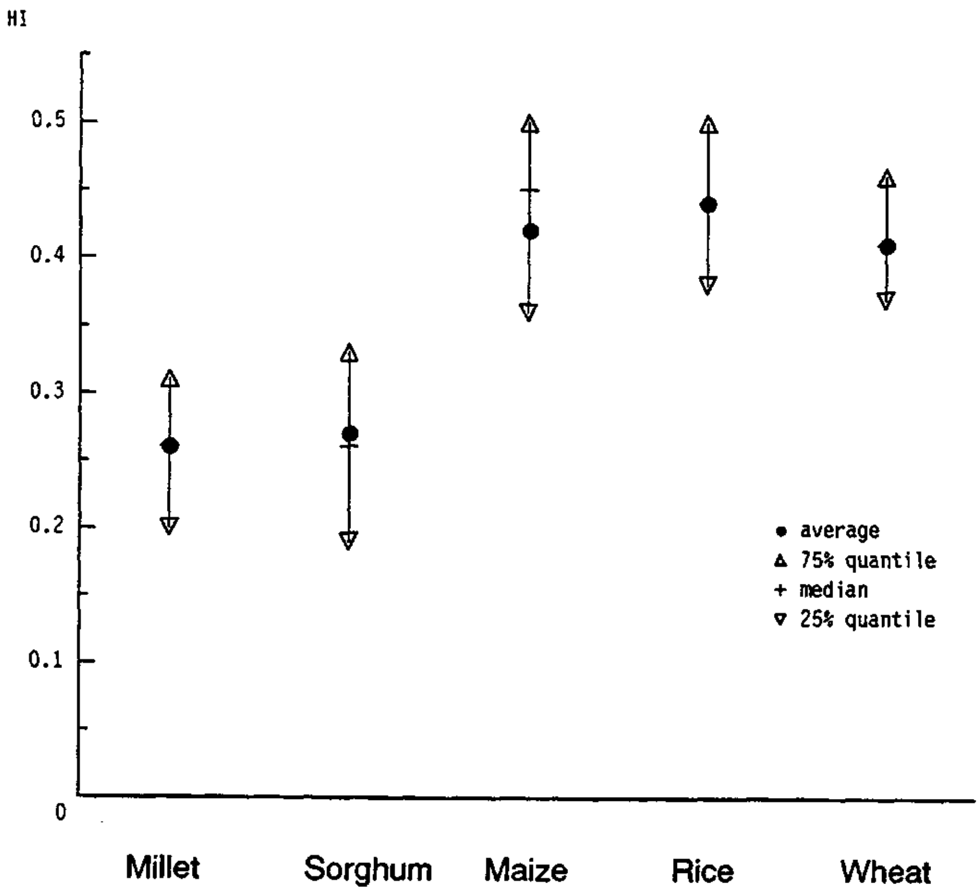


Figure 2.3. Characteristics of the frequency distribution of the harvest indices of various cereals world-wide.

Table 2.4. *Average and standard error (s.e.) of harvest index for five major cereals. Different letters ([a-e]) denotes a significant difference at 95% probability for each characteristic.*

	Millet	Sorghum	Maize	Rice	Wheat
average	0.26[a]	0.27[a]	0.42[b]	0.44[b]	0.41[c]
s.e.	0.08	0.11	0.12	0.08	0.07
(n)	(480)	(306)	(344)	(392)	(329)

For other crops such an analysis has not been performed, due to time restrictions and data availability. The average and range for each data set for these crops are tabulated in Chapters 10 to 14.

Other relevant information, in relation to partitioning of total aboveground biomass, is the fruitharvest index (FHI) and grain-fruit ratio (GFR) of leguminous species. The FHI is defined as the weight ratio of grains and podshells to total aboveground biomass, and the GFR as the weight ratio of grains to grains and podshells. These indices are presented for groundnut in Tables 11.2 and 11.3, for cowpea in Tables 12.2 and 12.3 and for bambara groundnut in Tables 13.1 and 13.2, respectively.

2.3.2 Minimum and average nutrient concentrations

Values of minimum concentrations for both marketable product and crop residues for the various crops should have been derived from results of chemical analyses of plants grown under nutrient-limiting conditions. However, as data referring to these conditions are scarce, the lowest values found in fertilizer experiments (Part B) have been defined as minimum concentrations (Table 2.5). With respect to those data, it should be realized that the original data may not be comparable because of different methods applied and for some crops remarks have been made (Section 5.3 - 14.3).

Average concentrations of the macro-nutrients in grains and straw at maturity of five cereals world-wide have been calculated (Table 2.6). Frequency distribution of these values is presented in Figure 2.4.

Table 2.5. *Observed minimum concentrations [g kg^{-1}] of major elements (ELE) in straw, pods and grains of the various crops, as applied for the Fifth Region of Mali.*

ELE	MILLET		SORGHUM		MAIZE		RICE	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
N	2.5	13.0	2.5	10.9	4.5	11.0	4.0	8.5
P	0.3	1.8	0.2	1.3	0.2	1.6	0.3	1.3
K	10.0	3.0	6.0	2.5	8.0	2.5	6.0	2.0
Ca	1.0	0.2	1.1	0.2	2.2	0.5	1.0	0.2
Mg	0.8	0.8	0.8	0.9	1.1	0.8	1.2	1.0
S	0.4	0.8	0.4	0.8	0.4	0.7	0.4	0.6

ELE	WHEAT[1]		FONIO*		COTTON*	
	Straw	Grain	Straw	Grain	Straw	Grain
N	2.3	12.9	5.0	12.3	7.3	23.3
P	0.3	2.1	.[2]	2.1	0.9	4.1
K	7.0	3.1	.[2]	2.8	11.1	10.1
Ca	.	.	.	0.7	5.3	1.3
Mg	0.4	0.9	.	0.9	1.5	2.7
S	.	.	.	.	1.5	2.3

ELE	GROUNDNUT			BAMBARA GROUNDNUT*			COWPEA		
	Straw	Pod	Grain	Straw	Pod	Grain	Straw	Pod	Grain
N	11.6	7.0	43.2	13.0	11.0	35.0	19.0	.[3]	25.6
P	1.0	0.4	2.2	0.9	0.7	3.0	1.1	.[3]	3.0
K	3.4	4.0	6.0	6.8	8.0	12.0	11.0	.[3]	15.7
Ca	6.8	0.7	0.3	14.6	.	0.8	25.9	.	0.7
Mg	2.2	0.6	1.7	3.2	.	1.8	4.9	.	1.8
S	1.7	1.0	2.2	.	.	1.0	.	.	.

*) limited data set available.
1) Wheat is not considered as potential crop for the region
2) Value of millet used for calculations performed
3) Value of groundnut used for calculations performed
. = unknown.

Table 2.6. *Average and standard error (s.e.) of nitrogen, phosphorus and potassium concentration [g kg^{-1}] in grain and straw (including rachis) of five major cereals (n = number of observations). Different letters ($^{a-e}$) denotes a significant difference at 95% probability for each characteristic.*

	Millet	Sorghum	Maize	Rice	Wheat
Nitrogen					
average of grain	18.5^{a}	16.9^{b}	15.5^{c}	11.6^{d}	21.4^{e}
s.e.	3.9	2.9	3.0	1.9	4.8
(n)	(125)	(139)	(267)	(184)	(243)
average of straw	7.0^{a}	6.5^{a}	6.6^{ac}	6.2^{ad}	5.1^{b}
s.e.	3.3	2.2	1.8	1.8	2.6
(n)	(99)	(105)	(183)	(171)	(200)
Phosphorus					
average of grain	3.1^{a}	2.6^{b}	2.9^{a}	2.0^{c}	3.7^{d}
s.e.	0.5	0.6	0.8	0.6	0.8
(n)	(86)	(75)	(101)	(171)	(53)
average of straw	0.9^{a}	0.8^{a}	0.8^{a}	1.1^{b}	0.5^{c}
s.e.	0.4	0.5	0.4	0.6	0.2
(n)	(86)	(73)	(82)	(158)	(46)
Potassium					
average of grain	4.8^{a}	3.4^{b}	3.5^{b}	3.9^{b}	4.6^{a}
s.e.	1.3	0.8	1.6	1.5	1.2
(n)	(70)	(27)	(45)	(105)	(65)
average of straw	20.9^{a}	10.9^{b}	11.6^{b}	18.9^{a}	15.9^{c}
s.e.	5.7	3.6	5.0	6.7	5.6
(n)	(70)	(27)	(41)	(105)	(65)

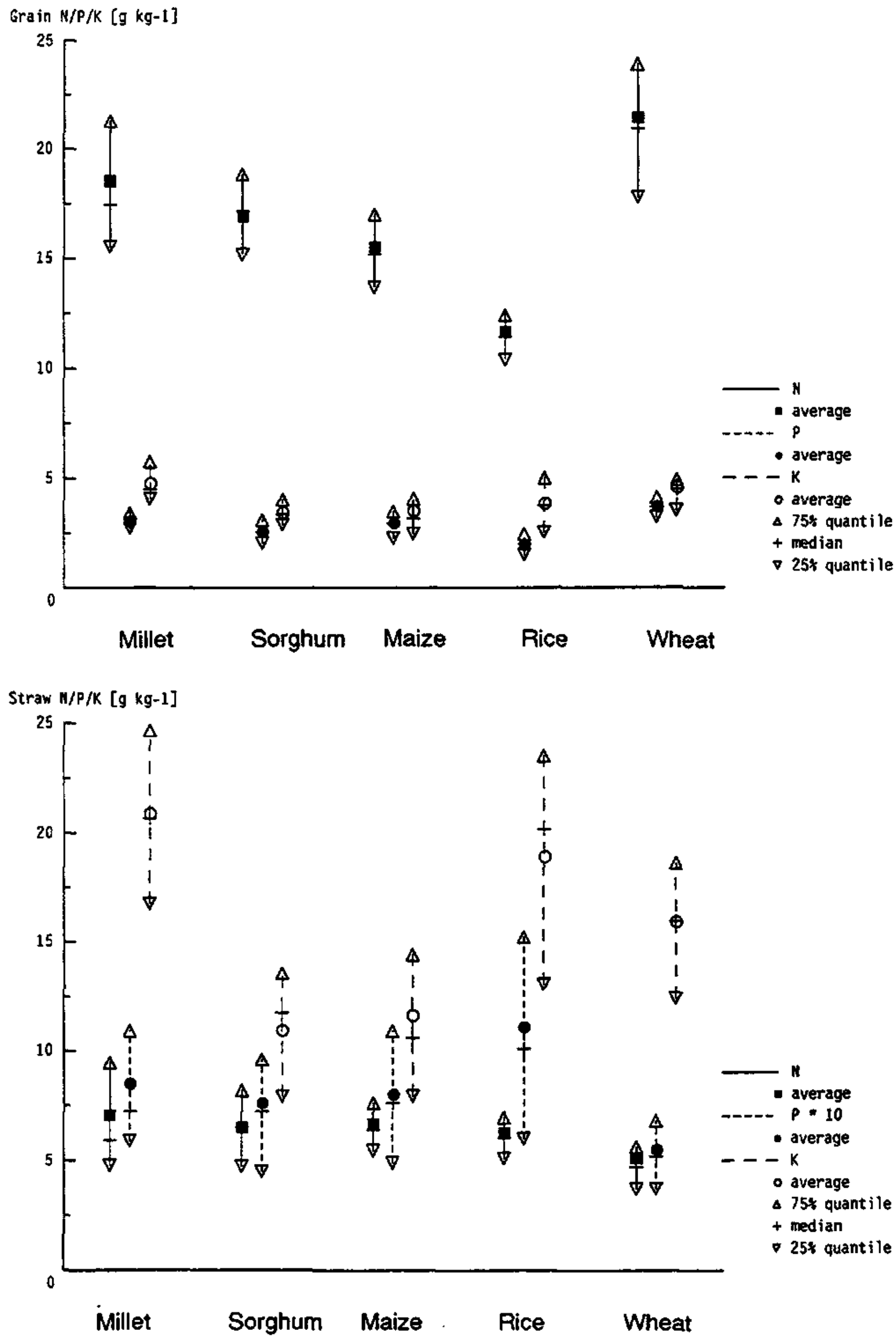


Figure 2.4. *Characteristics of the frequency distribution of nitrogen, phosphorus and potassium concentration in grain and straw of various cereals world-wide.*

2.3.3 *Nutrient harvest indices*

Nutrient harvest indices are defined as the ratio of nutrient content in the marketable product and in total aboveground dry matter. It also give information about the translocation from vegetative organs to reproductive organs in combination with the relative post-anthesis nutrient uptake or nutrient content at flowering. For nitrogen, this determines to a large extent potential grain yield (van Keulen & Seligman, 1987). In addition, the nutrient content of the grain determines its quality, hence is of importance for human consumption and in some cases also for animal consumption (e.g. van Duivenbooden, 1989).

Nutrient harvest indices are, generally, dependent on *(i)* genetic properties, determining nutrient concentrations in plant organs (e.g. Subramanian *et al.*, 1990; Alagarswamy & Bidinger, 1987; Seetharama *et al.*, 1987; Chevalier & Schrader, 1977), *(ii)* climatological conditions, e.g. drought periods (e.g. Johnston & Fowler, 1991) and *(iii)* fertilizer application, for instance, in rice and millet it has been observed that potassium harvest index decreased with increasing K-application rates (Gill & Kamprath, 1990; Piéri, 1979). The mechanism behind this latter observation is not explained, but relative shortages of phosphorus and nitrogen may play a role. Furthermore, the degree of N-lock-up (N irreversible incorporated in vegetative plant material) is important for the nitrogen harvest index, as reported for wheat by Eilrich & Hageman (1973).

Figure 2.5 presents the main characteristics of the frequency distribution of the macro-nutrient harvest indices for the five cereals, the averages being summarized in Table 2.7.

Table 2.7. *Average values and standard errors (s.e.) of nitrogen (NHI), phosphorus (PHI) and potassium (KHI) harvest index for five major cereals. Different letters ($^{a-e}$) denotes a significant difference at 95% probability for each characteristic.*

	Millet	Sorghum	Maize	Rice	Wheat
NHI					
average	0.47^{a}	0.58^{b}	0.66^{c}	0.61^{d}	0.74^{e}
s.e.	0.13	0.11	0.11	0.10	0.08
(n)	(132)	(146)	(357)	(188)	(355)
PHI					
average	0.53^{a}	0.61^{b}	0.67^{c}	0.61^{b}	0.78^{d}
s.e.	0.12	0.12	0.13	0.13	0.07
(n)	(87)	(84)	(122)	(181)	(59)
KHI					
average	0.08^{a}	0.12^{b}	0.20^{c}	0.17^{c}	0.16^{c}
s.e.	0.05	0.08	0.14	0.11	0.05
(n)	(72)	(35)	(84)	(146)	(68)

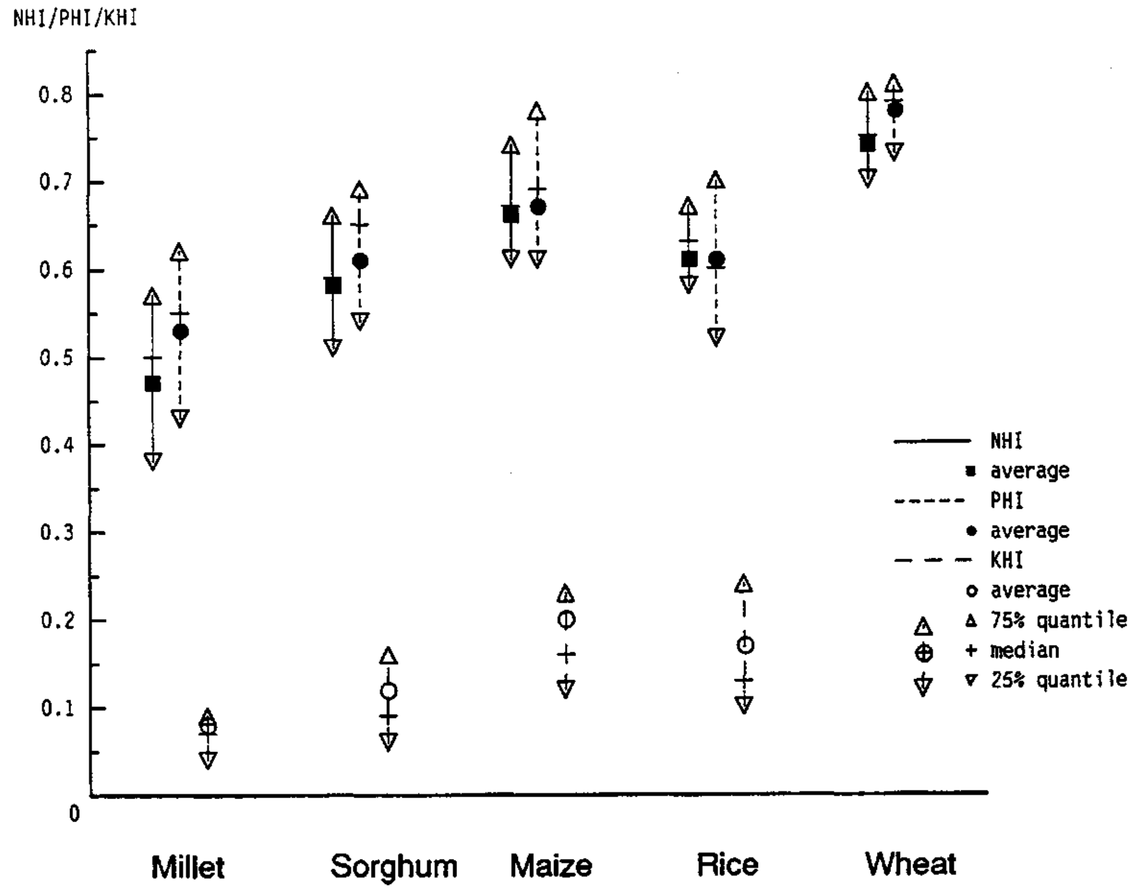


Figure 2.5. *Characteristics of the frequency distribution of nitrogen (NHI), phosphorus (PHI) and potassium (KHI) harvest indices of various cereals world-wide.*

Sources: Millet: Balasubramanian & Nnadi, 1981; Bationo & Mokwunye, 1991; Bertrand et al., 1972; Blondel, 1971a; Coaldrake & Pearson, 1985; van Duivenbooden & Cissé, 1989; Ganry, 1990; Gigou, 1984; Gosseye, unpublished; Jenny, 1974; Jones, 1976; Nabos et al., 1974; Pichot et al., 1974; Piéri, 1979; Sharma & Swarup, 1989; Singh & Thakare, 1986; Traoré, 1974; Vidal, 1963; Wani et al., 1990;

Sorghum: Arrivets, 1976; Balasubramanian & Nnadi, 1981; Bennett et al., 1990; Blondel, 1971a; Déat et al., 1976; Dupont de Dinechin, 1968; Duncan & Baligar, 1990; Jacquinot, 1964; Jenny, 1974; Gigou, 1981, 1984; Locke & Hons, 1988; Maranville et al., 1980a; Myers, 1978a,b; Muchow, 1990; Pal et al., 1982; Perry & Olson, 1975; Rai, 1965a,b; Seetharama et al., 1987; Singh & Bains, 1973; Turkhede & Prasad, 1980;

Maize: Ahlawat et al., 1981; Allison, 1984; Anderson et al., 1984b; Beauchamp et al., 1976; Balasubramanian & Nnadi, 1981; Bigeriego et al., 1979; Blondel, 1971a; Dass & Singh, 1979; Deckard et al., 1973; De Datta, 1985; Duncan & Baligar, 1990; Dupont de Dinechin, 1968; di Fonzo et al., 1982; Ganry, 1990; Gigou & Chabalier, 1987; Grove et al., 1980; Hanway, 1962; Hay et al., 1953; Jenny, 1974; Jordan et al., 1950; Jones, 1976; Kang & Osiname, 1979; Kang & Yunusa, 1977; Kang et al., 1977; Loué, 1963; Lubet & Juste, 1985; Maddux et al., 1991; Mehla & Singh, 1980; Moll et al., 1982; 1987; Ofori & Stern, 1987; Peck & MacDonald, 1975; Perry & Olsen, 1975; Pollmer et al., 1979; Rai, 1965a,b; Sayre, 1948; Selke, 1940; Singh & Balasubramanian, 1983; Sisworo et al., 1990; Sparks et al., 1980; Thiagalingam et al., 1991; Thiraporn et al., 1983; Thom & Watkin, 1978; Traoré, 1974; Zuber et al., 1954;

Rice: Agarwal, 1980; Balasubramanian & Nnadi, 1981; Beye, 1973a, 1974; Blondel, 1971a; Bredero, 1966; Bushan & Singh, 1979; De Datta, 1981; 1985; De Datta & Mikkelsen, 1985; De-Yin & Bao, 1985; Duncan & Baligar, 1990; Gigou & Chabalier, 1987; Gill & Kamprath, 1990; Humphreys et al., 1987; Imai, 1991; Jenny, 1974; Majumdar, 1973; Mahapatra & Pande, 1972; Palmer et al., 1990; Reddy & Patrick, 1976, 1978; Sharma & Mittra, 1991; Siband, 1972; Siband & Diatta, 1974; Singh & Modgal, 1978, 1979; Singh & Singh, 1987a,b; Sisworo et al., 1990; Traoré, 1974; Velly, 1972; Yoshida, 1981;

Wheat: Atanasiu et al., 1978b; Balasubramanian & Nnadi, 1981; Bishop & MacEachern, 1971; Black et al., 1946; Boatwright & Haas, 1961; Cassman et al., 1992; Cox et al., 1985; Duncan & Baligar, 1990; Eilrich & Hageman, 1973; Ellen & Spiertz, 1975, 1980; Groot, 1987; Hamid, 1973; Hamid & Sarwar, 1977; Johnston & Fowler, 1991; Jones et al., 1981; Khetawat et al., 1972; Lal & Sharma, 1974; Lal et al., 1978; Maliwal, 1990; McNeal et al., 1966; Mohamed & Marschall, 1979; Orphanos & Krentos, 1980; Paccaud et al., 1985; Papakosta & Gagianas, 1991; Racz et al., 1965; Selke, 1940; Singh & Balasubramanian, 1983; Spiertz & Ellen, 1978; Spiertz & de Vos, 1983; Spinks & Barber, 1947; Stapper & Fischer, 1990; Talati et al., 1974; Thorne et al., 1988; Verstraeten & Livens, 1975; Waldren & Flowerday, 1979; Woodruff, 1972.

The relationship between dry matter harvest index and nitrogen harvest index (NHI) and between phosphorus harvest index and NHI is also examined (Millet: Figure 5.12, sorghum: Figure 6.11, maize: Figure 7.11, rice: Figure 8.12 and wheat: Figure 9.11). However, these linear relations are spurious (Kenney, 1982; Reed, 1921), which means that any combination of the two data set will yield a linear relation because they have a common factor (i.e. HI).

Furthermore, the relationship post-anthesis nutrient uptake to its associated harvest index was examined (Millet: Figure 5.13, sorghum: Figure 6.12, maize: Figure 7.12, rice: Figure 8.13 and wheat: Figure 9.12).

2.4 Nutrient content as related to yield

2.4.1 General description

Although the moment of maximum content does not always coincide with maturity (Subsection 2.2.2), for evaluation of the relation between nutrient content and biomass production, nutrient content at maturity has been used.

The relation between content of a nutrient and yield is generally linear at low uptake levels; at higher levels it deviates from linearity, reflecting higher concentrations of the nutrient in the tissue (grains and straw) at harvest. Finally, the curve levels off, indicating that the nutrient under consideration is no longer a constraint for unrestricted growth. The parameters describing that relation are thus initial slope ('use efficiency'), inflection point and maximum level.

The initial slope and the variation between individual points for each nutrient are determined by many factors and their interactions. They include:

1. Crop species and variety;
2. Harvest index. Generally, a higher harvest index will imply a higher content to yield ratio;
3. Weather conditions, especially rainfall. Water shortage, particularly during the reproductive stage may cause accelerated senescence of the leaf blades, hence, reduced rates of photosynthesis. Nitrogen is generally incorporated preferentially in the young tissue and diluted during further development. Interruption of the flow of carbohydrates to the filling grain due to reduced assimilation, results in grains with a high protein content and the initial slope decreases considerably, even under limited supply (van Keulen & van Heemst, 1982). In addition, under water shortage, translocation of nitrogen from vegetative material to the grains may be hampered (e.g. Hanson & Hitz, 1983), so that vegetative material may die with a high nitrogen content. Such situations result in a low content to yield value;
4. Translocation capacity of the crop. Crops with a low translocation capacity will end up with high concentrations in the straw and consequently a low content to yield value;
5. Post-anthesis uptake. If post-anthesis uptake is sufficiently high (Subsection 2.2.1), concentrations in straw can remain high and if the uptake rate can keep pace with the nutrient demand of the grains, also the concentration in the grain will be high. In some cases (e.g. wheat, Spiertz & Ellen, 1978), however, post-anthesis uptake did not result in higher yields, but in a lower yield/content ratio;

6. The moment of maximum nutrient content (Subsection 2.2.2);
7. Availability of other nutrients. If one of the other macronutrients is available in limited supply, this may result in increased uptake of the nutrient considered ('luxury consumption'), resulting in a lower value of the content to yield ratio;
8. Management practices. A special place in agricultural production systems have ratoon crops. Ratooning is a practice to obtain a second harvest from a crop (ratoon tillers develop from basal auxiliary buds on the stubble of the main stem). Time of fertilizer application is important for biomass production (e.g. Ichii, 1988). N-application before harvest of the main crop reduces to some extent its yield of the first crop, but promotes development of dormant buds and increases yield of the ratoon crop (Sun *et al.*, 1988). Also Escalada & Plucknett (1981) concluded that for a successful sorghum ratoon crop, high N-applications rates are necessary. Borden (1944) concluded that ratoon sugar cane had a lower nitrogen use efficiency than without ratooning.
9. Finally, the notation P and K has been used for P_2O_5 and K_2O, respectively. On the basis of plant tissue concentrations, sometimes this confusion could be cleared (Subsection 2.3.3).

The level of the plateau is determined by the growth factor in short supply and is, in the 'potential growth' situation, a function of available solar energy during the plant's growth period (van Keulen, 1982).

2.4.2 Nitrogen

The relationship N-content to yield is presented graphically in detail for all crops in Part B. Here, that relation is discussed for five major cereals: millet, sorghum, maize, rice and wheat (Figure 2.6). In this figure the average slope (YNA) is given, and the envelope of all points is called the initial slope or initial nitrogen use efficiency (YNI).

For the initial slope of the relation N-content to yield (Figure 2.6), sorghum and rice show the highest values (80 kg kg^{-1}), maize and wheat somewhat lower, and millet the lowest (45 kg kg^{-1}). Also the average value is highest for rice (54 kg kg^{-1}) and lowest for millet (26 kg kg^{-1}). The other three cereals show similar values (37-41 kg kg^{-1}), which are significantly different, except among sorghum and wheat (Table 2.8). Within a species, environmental and genetic differences have no effect on the initial slope, except for millet. It differs among two major agro-ecological zones, i.e. 35 kg kg^{-1} in Senegal and 45 in India, being mainly the result of a higher harvest index in India, 0.28 versus 0.22 (Chapter 5).

On the basis of the relevant figures presented in Part B, the eye-fitted initial slopes have been summarized for all crops in West Africa in Table 2.9.

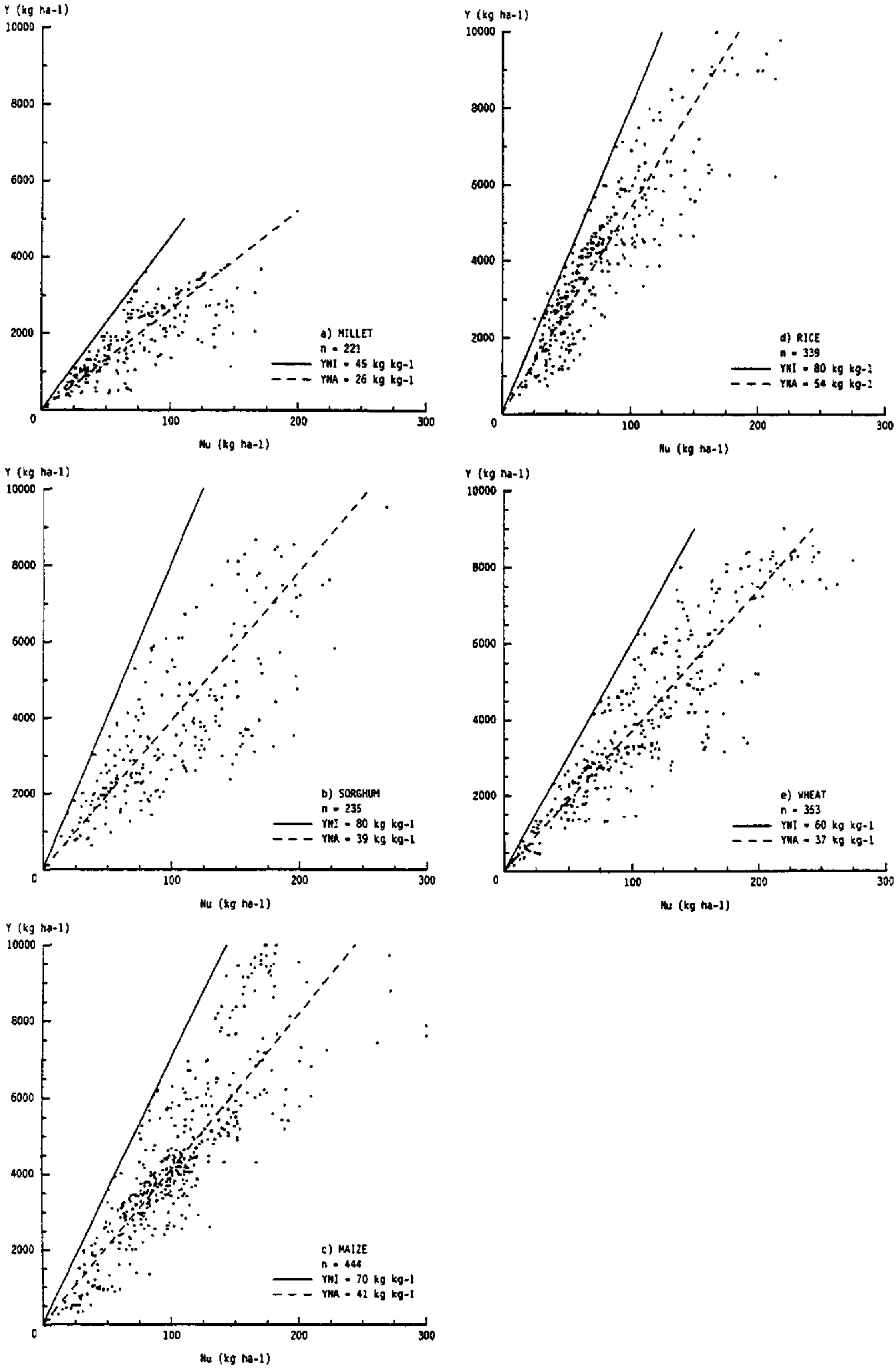


Figure 2.6. *The relation between total nitrogen content (N_u) and grain yield for millet, sorghum, maize, rice and wheat. YNI = initial nitrogen use efficiency and YNA = average ratio yield/N-content.*

Table 2.8. *25% quantile, median, 75% quantile, average and standard error (s.e.) of grain yield nitrogen content at maturity [kg kg^{-1}] for five major cereals (n = number of observations). Different letters ($^{a-d}$) denotes a significant difference at 95% probability.*

	Millet	Sorghum	Maize	Rice	Wheat
25% quantile	21	29	35	45	32
median	27	36	40	55	37
75% quantile	31	46	48	63	43
average	26^{a}	39^{b}	41^{c}	54^{d}	37^{b}
s.e.	8	13	11	13	9
(n)	(227)	(235)	(444)	(339)	(353)

Table 2.9. *Observed initial slope of grain yield and nitrogen content at maturity [kg kg^{-1}] and calculated indicative values on the basis of harvest index (HI), fruit-harvest index (FHI) and grain/fruit ratio (GFR) and minimum concentration and multipliers for major crops in West Africa.*

CROP	HI	FHI	GFR	Observed slope	Minimum concentration * 1.3	* 1.7
Millet	0.22			45	35	27
Sorghum	0.20			80	37	28
Maize	0.41			70	44	34
Rice	0.45			80	56	43
Wheat	0.42			60	49	37
Fonio	0.15			-	19	14
Groundnut*		0.35	0.70	30	18	13
Cowpea		0.30	0.60	32	12	9
Cotton	0.20			47	15	11

*) unshelled.

The values of the observed initial slopes (Table 2.9) differ from those applied by van Keulen & Breman (1990), which are generally higher, indicating that the nutrients are further diluted. Also values reported by Janssen *et al.* (1990) for maize are higher than those in Table 2.9: 70 versus 58 for nitrogen. The reason for these differences are not fully understood, and further investigations in this area are necessary. As mentioned earlier, this envelope represents the observed slope for nutrients at maximum dilution. However, in agricultural practice such a dilution seems not realistic due to various reasons (e.g. lack of rainfall, other nutrients limiting, etc.). Therefore, a multiplier has been introduced, its value dependent on system intensity. Using the distribution of biomass as presented in Subsection 2.3.1, the minimum concentrations of N, P and K (Table 2.5) and the multiplier defined for semi-intensive systems (i.e. 1.3, Section 3.2), the slopes are calculated (Table 2.9). As a consequence of the introduction of the multiplier, the values are lower than the initial slope, but compared to the majority of points in the relevant figures, the values are still relatively high. This means that the value of 1.3 results in an underestimate of nutrient uptake; for intensive systems, a value of 1.7 seems more appropriate (Table 2.9).

2.4.3 Phosphorus

For the relationship of P-content to yield (Figure 2.7), rice show the highest initial slope (850 kg kg^{-1}) and millet the lowest (350 kg kg^{-1}). It is more or less similar in sorghum and wheat (500 kg kg^{-1}) and somewhat higher in maize (600 kg kg^{-1}). Average slopes show the same ranking, with the difference among sorghum and wheat not significant (Table 2.10).

On the basis of the relevant figures presented in Part B, the eye-fitted initial slopes and calculated indicative values have been summarized for all crops in West Africa in Table 2.11.

Table 2.10. *25% quantile, median, 75% quantile, average and standard error (s.e.) of grain yield and phosphorus content at maturity [kg kg^{-1}] for five major cereals (n = number of observations). Different letters ($^{a-d}$) denotes a significant difference at 95% probability.*

	Millet	Sorghum	Maize	Rice	Wheat
25% quantile	139	204	202	250	206
median	186	229	285	326	231
75% quantile	237	297	336	412	311
average	194^{a}	249^{b}	279^{c}	363^{d}	252^{b}
s.e.	67	70	93	150	72
(n)	(166)	(132)	(249)	(303)	(138)

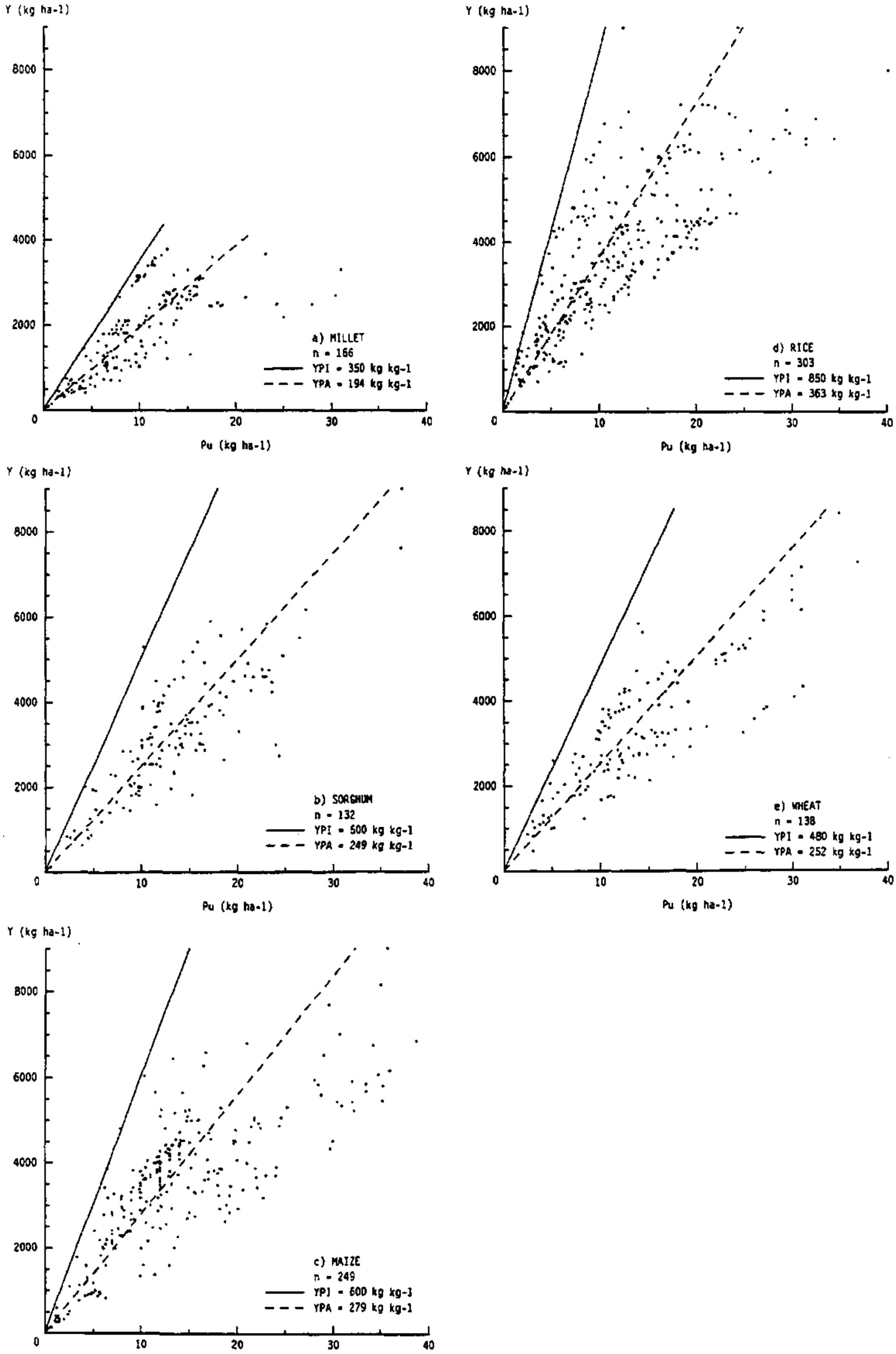


***Figure 2.7**. The relation between total phosphorus content (P_u) and grain yield for millet, sorghum, maize, rice and wheat. YPI = initial phosphorus use efficiency and YPA = average ratio yield/P-content.*

Table 2.11. *Observed initial slope of grain yield and phosphorus content at maturity [kg kg⁻¹] and calculated indicative values on the basis of harvest index (HI), fruit-harvest index (FHI) and grain/fruit ratio (GFR) and minimum concentration and multipliers for major crops in West Africa.*

CROP	HI	FHI	GFR	Observed slope	Minimum concentration * 1.3	* 1.7
Millet	0.22			350	269	205
Sorghum	0.20			500	366	280
Maize	0.41			600	407	312
Rice	0.45			850	453	346
Wheat	0.42			480	312	238
Fonio	0.15			-	202	155
Groundnut*		0.35	0.70	470	289	221
Cowpea		0.30	0.60	300	151	115
Cotton	0.20			290	100	76

*) unshelled.

2.4.4 Potassium

The initial slope of the relationship K-content to yield varies more than for the other two nutrients, for two reasons. Firstly, at maturity the larger part of the potassium is in the straw. Consequently, variations in harvest index have a stronger effect on the initial slope than for nitrogen and phosphorus. Secondly, potassium has a double function in the plant: it is needed for certain physiological functions (osmotic and ionic regulation, cofactor and activator for many enzymes of carbohydrate and protein metabolism, Baligar *et al.*, 1990), but also serves as a positive charge, accompanying organic and inorganic anions during transport through the plant (van Keulen & van Heemst, 1982). This means that the relation K-content to yield is difficult to interpret and instead, the relation to total aboveground biomass is used.

For the five major cereals, this relationship is presented in Figure 2.8, whereas in Part B more detailed figures are presented for all crops. Data on the relationship of K-content to total aboveground biomass (Figure 2.8) are more scarce than on the preceding relationships. Here, sorghum, maize and rice show more or less the same initial slope (200 kg kg^{-1}), wheat a somewhat lower slope (170 kg kg^{-1}) and millet the lowest (100 kg kg^{-1}). Average values are highest for maize and sorghum (119-126 kg kg^{-1}, not statistically different, Table 2.12), somewhat lower for wheat (107 kg kg^{-1}) and rice (92 kg kg^{-1}) and lowest for millet (64 kg kg^{-1}).

On the basis of the relevant figures presented in Part B, the eye-fitted initial slopes and calculated indicative values have been summarized for all crops in West Africa in Table 2.13.

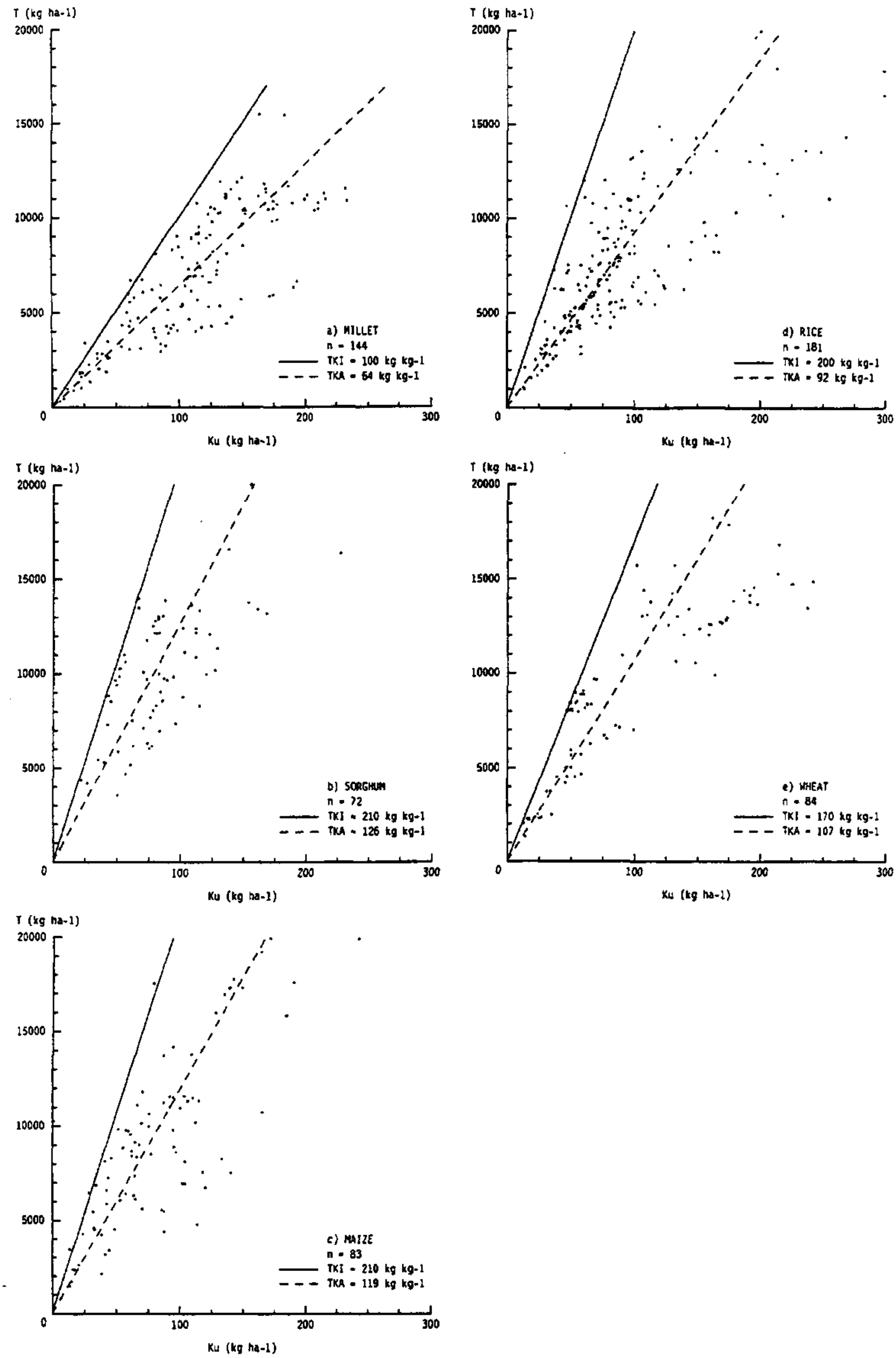


***Figure 2.8.** The relation between total potassium content (K_u) and total aboveground biomass (T) for millet, sorghum, maize, rice and wheat. TKI = initial potassium use efficiency and TKA = average ratio total aboveground biomass/K-content.*

Table 2.12. 25% quantile, median, 75% quantile, average and standard error (s.e.) of total aboveground dry matter to potassium content at maturity [kg kg^{-1}] for five major cereals (n = number of observations). Different letters ($^{a-d}$) denotes a significant difference at 95% probability.

	Millet	Sorghum	Maize	Rice	Wheat
25% quantile	52	97	92	68	78
median	63	117	120	89	100
75% quantile	78	156	142	109	134
average	64^a	126^b	119^b	92^c	107^d
s.e.	18	40	40	32	33
(n)	(144)	(72)	(83)	(181)	(84)

Table 2.13. Observed initial slope of total aboveground dry matter and potassium content at maturity [kg kg^{-1}] and calculated indicative values on the basis of harvest index (HI), fruit-harvest index (FHI) and grain/fruit ratio (GFR) and minimum concentration and multipliers for major crops in West Africa.

CROP	HI	FHI	GFR	Observed slope	Minimum concentration * 1.3	* 1.7
Millet	0.22			100	91	70
Sorghum	0.20			210	145	111
Maize	0.41			170	134	102
Rice	0.45			200	142	109
Wheat	0.42			170	147	112
Fonio	0.15			-	86	66
Groundnut*		0.35	0.70	200	175	134
Cowpea		0.30	0.60	80	70	53
Cotton	0.20			155	71	54

*) unshelled.

Unlike for nitrogen and phosphorus, scatter in the relation of K-content to total aboveground biomass can substantially be reduced, namely by combining K with the uptake of other cations like magnesium (Mg) and calcium (Ca). The combined content of K+Ca+Mg at maturity is linearly related to total aboveground biomass. For rice (Figure 8.8) the correlation factor is lower than for millet, sorghum and maize (Figures 5.9, 6.8 and 7.8, respectively), and the value for wheat (figure 9.8) should not be overestimated, as only two observations were available. The linearity of this relation indicates that these three elements are available in the soil in sufficient amounts and that some functions in which potassium plays a role can be taken over by Mg or Ca (van Keulen & van Heemst, 1982; de Wit *et al.*, 1963). Calcium regulates then osmotic and inonic processes (membranes) and magnesium works as cofactor in enzymatic reactions (Baligar *et al.*, 1990).

For a theoretical dry matter production of 10 ton, millet and rice show the highest K+Ca+Mg-content (217 kg kg^{-1}), sorghum and maize a considerably lower content (about 130 kg kg^{-1}), while wheat shows the lowest (92 kg kg^{-1}).

2.5 Nutrient content as related to nitrogen content

The ratio of nutrient content to nitrogen content in total aboveground dry matter at maturity is an additional variable, useful in the interpretation of fertilizer experiments. For the P/N ratio an optimum value has been defined (Penning de Vries & van Keulen, 1982), but not for others.

2.5.1 P/N

The P/N ratio is an important parameter, indicating the relative availability of phosphorus and nitrogen. Penning de Vries & van Keulen (1982) observed in Sahelian grasses at flowering a range in the P/N ratio of 0.04 to 0.15. They considered 0.10 as optimum, lower values indicating a relative shortage of phosphorus, higher values a relative shortage of nitrogen. Especially old and well fertilized plants show sometimes a P/N ratio that considerably exceeds 0.15 (Penning de Vries *et al.*, 1980). Here that relation is evaluated for crops at maturity.

The P/N ratio ranges in millet and sorghum from 0.06 to 0.34, in maize from 0.05 to 0.28, in rice from 0.04 to 0.31, in wheat from 0.10 to 0.31 (Figure 2.9). The P/N ratio for groundnut and cowpea ranges in West Africa from 0.04 to 0.10 (Figure 11.7) and from 0.11 to 0.57 (Figure 12.7), respectively, and it ranges from 0.13 to 0.32 in cotton (Figure 14.5). Differences in average P/N ratio among the five major cereals are small, despite their large differences in growing conditions; rice shows the highest average value (0.17), followed by wheat (0.16), millet, sorghum and maize (0.14-0.15). The difference among the last three species is not significant (Table 2.14).

Table 2.14. *Average and standard error (s.e.) of the P/N ratio in five major cereals. * denotes significant difference at 95% probability (n = number of observations).*

	Millet	Sorghum	Maize	Rice	Wheat
average	0.14^a	0.15^a	0.14^a	0.17^b	0.16^c
s.e.	0.06	0.06	0.04	0.06	0.04

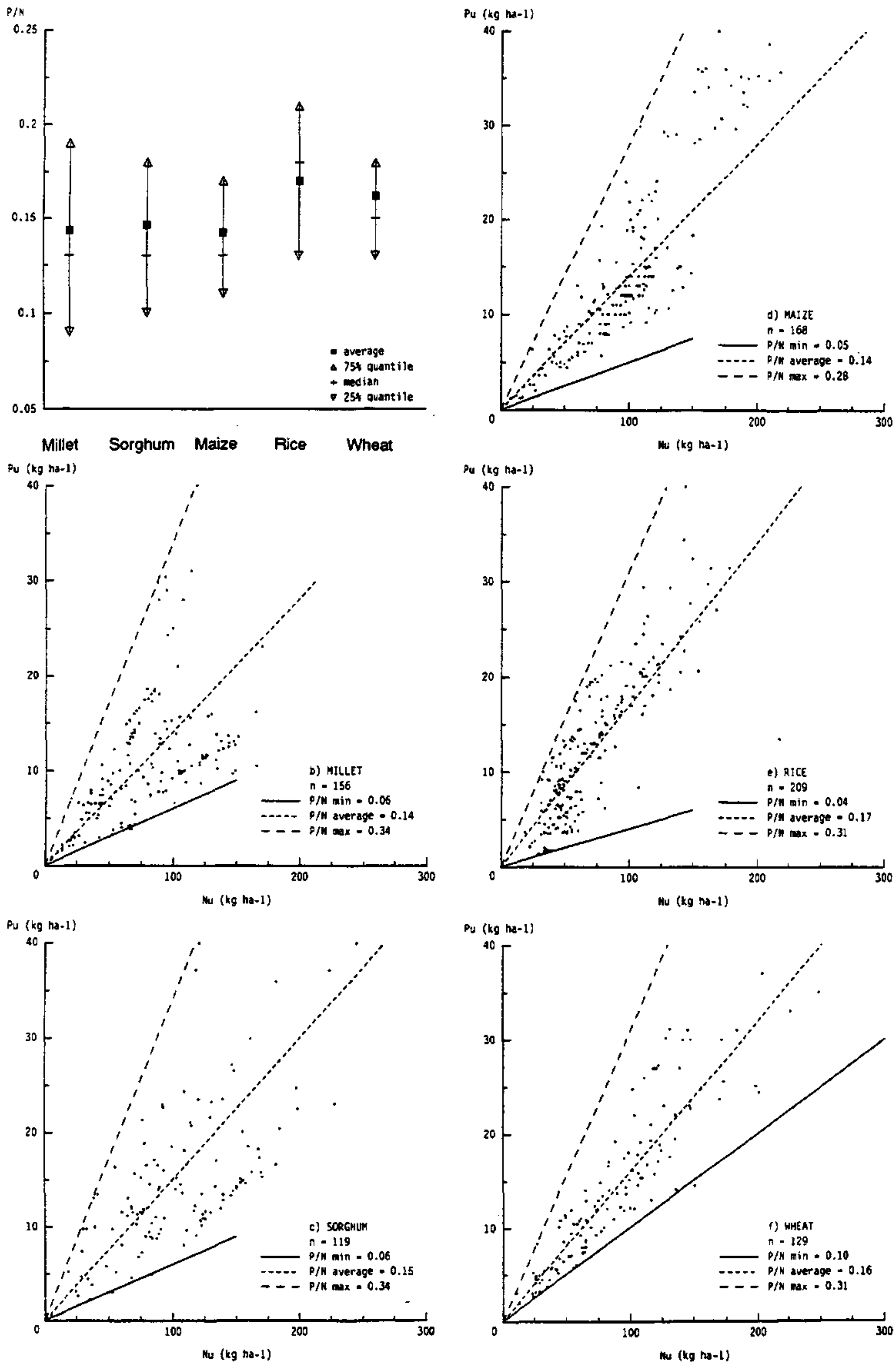


Figure 2.9. *The relation between total nitrogen content (N_u) and total phosphorus content (P_u) at maturity for millet, sorghum, maize, rice and wheat.*

The values of P/N ratio found in this study (Table 2.14) differ, however, considerably from those reported earlier by Penning de Vries *et al.* (1980) in grasses, ranging from 0.04 to 0.15, while values exceeding 0.15 were considered exceptional. The much higher values reported here, which for all five species exceeded 0.10 on average, would imply, according to their hypothesis, a relative shortage of nitrogen in many parts of the world. That seems unlikely, thus there should be another explanation for a high P/N ratio: either a low N-content or a high P-content or a combination of both.

A low N-content, implying maximum dilution and translocation, points to nitrogen as growth-limiting factor. This may have been the case, for instance, in an experiment with millet, where yield did not respond to increased phosphorus content (Piéri, 1979), but for other experiments this seems unlikely. Another contributor to a low N-content could be N-losses through *(i)* leaf fall, *(ii)* transport to the atmosphere in gaseous form, mainly as NH_3, but also as N_2 and NO_x (Farquhar *et al.*, 1983), *(iii)* leaching by rain (Gigou, 1984) and *(iv)* translocation to the roots (Arrivets, 1976). However, also for phosphorus losses are reported and the magnitude of these losses are about similar to those for N, as mentioned above. Hence, there seems no reason to assume that the P/N ratio at maturity differs from that at the moment of maximum content.

A possible explanation for an increase in P-content might be that phosphorus accumulates as PO_4^{2-} or HPO_4^- instead of organic anions, to maintain electro-neutrality at high uptake of K^+ (Ca^{2+} and Mg^{2+}) ions. However, information to test this hypothesis was lacking.

Another explanation for the deviating behaviour of cereals could be the difference in nutrient uptake in the course of the growing season. All the five species show the capacity to take up nutrients after flowering, in contrast to grasses (Subsection 2.2.1). During the post-anthesis period, average relative uptake of phosphorus exceeds that of nitrogen in sorghum, maize and wheat, but not in millet and rice. Hence, the P/N ratio in the latter two species must have even been higher at anthesis. Consequently, the value of 0.10 can not be considered optimum for cereals. On the basis of the following an alternative optimum P/N ratio is suggested.

In the relation nutrient content to yield (dry matter) the initial slope (100% quantile) indicates maximum dilution, hence a relative shortage of the nutrient considered, whereas the lowest values of the ratio yield and nutrient content (0% quantile, not drawn in the figures presented) indicate a relative surplus of the nutrient considered. On the basis of these considerations, it is hypothesized that the 25% and 75% quantiles (Tables 2.9 and 2.11) can be used as indicator for nutrient-limited crop growth. Values exceeding the 75% quantile indicate a relative shortage of the nutrient considered, whereas values below the 25% quantile indicate that other factors (e.g. other nutrients or environmental conditions) were limiting.

These hypothetical values are examined further through theoretical P/N ratios (Table 2.15). This table shows that under severe P-deficiency the P/N ratio is on average for the five species 0.06. If N and P are equally available (diluted or surplus) it is 0.15, and if N is in severe shortage it is 0.33. Therefore, the P/N ratio of 0.15 is considered optimum for cereal growth, and consequently values exceeding this value indicates a relative N-shortage and values below this value a relative P-shortage.

Table 2.15. Theoretical P/N ratios on the basis of the ratios yield to nutrient content at maturity from Table 1. YN = yield/N-content, YP = yield/P-content, 25 = 25% quantile, 50 = median, 75 = 75% quantile, 100 = initial slope = 100% quantile, and a = average.

	Millet	Sorghum	Maize	Rice	Wheat
P-shortage					
YN25/YP100	0.06	0.06	0.06	0.05	0.07
YN25/YP75	0.09	0.10	0.10	0.11	0.10
N & P equally available					
YN25/YP25	0.15	0.14	0.17	0.18	0.16
YN50/YP50	0.15	0.16	0.14	0.17	0.16
YNa/YPa	0.13	0.16	0.15	0.15	0.15
YN75/YP75	0.13	0.15	0.14	0.15	0.14
YN100/YP100	0.13	0.16	0.12	0.09	0.13
N-shortage					
YN75/YP25	0.22	0.23	0.24	0.25	0.21
YN100/YP25	0.32	0.39	0.35	0.32	0.29

2.5.2 K/N

For the West African conditions, the ratio of K-content to N-content at maturity for millet ranges from about 0.6 (van Duivenbooden & Cissé, 1989; Ndiaye, 1978) to 3 (Jenny, 1974; Piéri, 1979). For sorghum, these values are 0.5 (Jacquinot, 1964) and 2.7 (Gigou, 1986a; 1986b), for cowpea about 0.9 (Jacquinot, 1967; Nnadi *et al.*, 1976; RFMC, 1980) and for cotton 0.9 and 1.3 (Déat *et al.*, 1976).

2.5.3 S/N

For the West African conditions, the ratio of sulphur content to nitrogen content at maturity for millet ranges from 0.05 (Pichot *et al.*, 1974) to 0.30 (Jenny, 1974) and for sorghum from 0.06 (Jenny, 1974) to 0.32 (Tourte *et al.*, 1971). For other crops this relationship has not been worked out, due to lack of time (Examples are given e.g. by Kanwar & Mudahar, 1986).

2.5.4 Ca/N

For the West African conditions, the ratio of calcium content to nitrogen at maturity for millet ranges from 0.10 (Tourte *et al.*, 1971) to 0.35 (Traoré, 1974) and for sorghum from 0.04 (Tourte *et al.*, 1971) to 1.15 (Tourte *et al.*, 1964). For other crops this relationship has not been worked out, due to lack of time.

2.5.5 Mg/N

For the West African conditions, the ratio of total magnesium content to nitrogen at maturity for millet ranges from 0.20 (Jenny, 1974) to 0.52 (Piéri, 1983; 1985) and for sorghum from 0.08 (Tourte *et al.*, 1964) to 0.40 (Déat *et al.*, 1976). For other crops this relationship has not been worked out, due to lack of time.

2.6 Fertilizer recoveries

Fertilizer recoveries have been calculated in this report by linear regression between fertilizer application and total nutrient content at harvest. The relation between fertilizer application and nitrogen and potassium content is generally linear over the full range of applications. For phosphorus this linearity does not hold in general. At very high application rates, the capacity of the crop to take up, transform and synthesize the nutrient in its structural biomass may become limiting. This results in discontinuities in the relation, and therefore in the summarizing tables (Tables A1.1 - A1.3) the maximum value is given (either the application to which the linear relationship holds or maximum level of application) for those experiments which have been presented graphically in Part B. Although the method is originally intended for monofactorial experiments (either N or P or K), in Part B all combinations reported in literature (e.g. N-recovery under P fertilizer application) are given.

The intercept with the X-axis in Quadrant B (application = 0 kg ha^{-1}) provides information on supply from natural sources, governed by quantity and quality of the organic matter present in the soil. This value may vary from year to year due to effects of management and environmental conditions (rainfall, temperature) on the decomposition rate of organic matter, the immobilization or mineralization rate of the nutrient considered and the losses of these nutrients.

To distinguish between farmyard (and other forms of organic) manure and inorganic fertilizer as a source of nutrients for the crop, treatments with and without organic amendments are presented separately in Quadrant B. The effect of manure application in terms of nutrient supply is then represented by the distance between the two lines on the nutrient content (= X) axis.

2.6.1 Nitrogen

Schematically, fertilizer nitrogen applied to the soil may be distributed between five fractions: incorporated in soil organic matter, leached, lost by denitrification, volatilised or taken up by the crop. Soil erosion losses have been neglected.

Nitrogen fertilizer recovery (expressed in kg N taken up per kg N applied) varies considerably, depending among others on rainfall, availability of P, crop type, type of fertilizer and mode and time of application, as illustrated in the three-quadrant diagrams for millet (Figure 5.3), sorghum (Figure 6.3), maize (Figure 7.2), rice (Figure 8.2), wheat (Figure 9.2), groundnut (Figure 11.1) and cowpea (Figure 12.2). Table A1.1 summarizes the recovery fractions derived from these figures 5.3, 6.3, 7.2, 8.2, 9.2, 11.1 and 12.2 and from additional experiments reported in literature.

Some remarks can be made: striking is the low value of P3 Kolo in Niger in 1972 (Figure 5.3d). The source (Pichot *et al.*, 1974), indicates that a period of drought occurred at the end of the growing season, resulting e.g. in grains and straw saturated with N.

In one experiment involving organic manure, a recovery of 1.05 for sorghum has been observed in Burkina Faso by Arrivets (1976, Figure 6.3b). This indicates that more nitrogen could be taken up than applied in the form of inorganic nitrogen. Apparently, mineralization in organic manure was favourable, which is however not always the case (van Duivenbooden & Cissé, 1992).

Results from experiments with groundnut show that application of small amounts of N-fertilizer results in substantial increases in N-uptake, leading to 'apparent' recoveries, exceeding 4 kg kg^{-1}. This must be explained by the stimulating effect of small quantities of 'starter-N' on symbiotic nitrogen fixation (e.g. Summerfield *et al.*, 1978).

The higher average N-recovery fraction in wheat (Table 2.16), compared to those in millet, sorghum and maize, may be explained on one hand by the fact that wheat is grown under conditions where fertilizer use generally has a longer history. Recovery fractions increase with continued fertilizer application, as observed in grasslands in the Netherlands (van der Meer & van Uum-van Lohuyzen, 1986). On the other hand N-losses, as discussed above, are more likely to occur under tropical conditions than in temperate regions. For instance, N-losses from wheat at the end of the growing season were considerable in Argentina (Echeverria *et al.*, 1992), compared to negligible losses in the Netherlands (Spiertz & Ellen, 1978). These losses expressed as percentage of maximum content are for wheat on average 3%. Only sorghum show lower losses (1%), maize shows an equal value, and the other species show higher values (rice: 6% and millet 10%; Subsection 2.2.2). Hence, N-recovery fractions, measured at the moment of maximum uptake, would only have been slightly different among species.

2.6.2 Phosphorus

As for nitrogen, the phosphorus fertilizer recovery fraction varies considerably among experiments, as illustrated in the three-quadrant diagrams for millet (Figure 5.4), sorghum (Figure 6.4), maize (Figure 7.3), rice (Figure 8.3), wheat (Figure 9.3), groundnut (Figure 11.2) and cotton (Figure 14.1). Table A1.2 summarizes the recovery fractions derived from those experiments.

The possible distribution of fertilizer-P is among four fractions: fixed in the soil mineral fraction, incorporated in soil organic matter, residual P (available the year after application) and taken up by the plant (on average 10-16%, Table 2.16). A major cause of P-losses is fixation in clay particles. However, information that can be used to explain the observed differences in recovery fractions among the five species is scarce. P-losses at the end of the growing season can not make up that difference, as average P-losses, as fraction of the maximum content, range from 0% (sorghum) via 4-5% (millet, maize and wheat) to 9% (rice; Subsection 2.2.2).

Table 2.16. Minimum, 25% quantile, median, 75% quantile, maximum, average and standard error (s.e.) of recovery fractions of nitrogen, phosphorus and potassium for five major cereals (n = number of observations).

	Millet & Sorghum	Maize	Rice	Deep-water rice	Wheat
Nitrogen					
minimum	0.05	0.00	0.00	0.00	0.01
25% quantile	0.22	0.21	0.24	0.14	0.26
median	0.33	0.34	0.40	0.28	0.42
75% quantile	0.51	0.46	0.52	0.45	0.55
maximum	0.90	0.90	0.95	0.79	0.94
average	0.37	0.36	0.39	0.29	0.42
s.e.	0.18	0.19	0.19	0.21	0.20
(n)	(67)	(93)	(123)	(34)	(108)
Phosphorus					
minimum	0.03	0.00	0.00		0.00
25% quantile	0.09	0.02	0.05		0.04
median	0.14	0.13	0.10		0.07
75% quantile	0.20	0.18	0.16		0.17
maximum	0.44	0.70	0.45		0.33
average	0.16	0.13	0.12		0.10
s.e.	0.10	0.13	0.09		0.08
(n)	(31)	(46)	(61)		(31)
Potassium					
minimum	0.22	0.11	0.00		0.08
25% quantile	0.25	0.17	0.19		0.11
median	0.34	0.33	0.28		0.17
75% quantile	0.46	0.50	0.53		0.23
maximum	0.73	0.60	0.72		0.67
average	0.38	0.34	0.34		0.24
s.e.	0.20	0.19	0.21		0.22
(n)	(5)	(6)	(39)		(6)

2.6.3 Potassium

Experiments on crop response to potassium fertilizer are scarce. Piéri (1979) has carried out K-fertilizer experiments on both millet and groundnut. Ekambaram *et al.* (1975) concluded that for CO7 finger millet on 4 soil types grain and straw yields increased following K-application, but not significantly. Beye (1974) gives data on experiments with rice carried out on acid soils in south Senegal. However, as the potassium concentrations seem too low (Table 8.1), no three quadrant diagrams have been constructed for these experiments. Results are presented for millet (Figure 5.5), maize (Figure 7.4), rice (Figure 8.4), wheat (Figure 9.4) and groundnut (Figure 11.3). Table A1.3 summarizes the recovery fractions derived from those experiments and those from additional experiments from the literature.

The possible distribution of potassium is among four fractions: incorporated in soil organic matter, leaching, incorporated in the soil mineral fraction and taken up by the plant (on average 24-38%, Table 2.16). Due to the low number of K-recovery fractions only tentative conclusions can be drawn. The low K-recovery fraction for wheat may be associated with the high K-losses (35% of maximum content, Subsection 2.2.2). For millet these losses are 2%, for maize 7%, for sorghum 9% and for rice 13% (Subsection 2.2.2). Therefore, if the K-recovery fraction is calculated at the moment of maximum K-content, the value would be identical for all five species, except for wheat, that would have probably a higher value.

2.6.4 Sulphur

Sulphur is important for growth of legumes. One experiment with sulphur application on cowpea has been found in literature (Fox *et al.*, 1977), but unfortunately a mixture of N, P and S was applied (Figure 12.3).

Effects of sulphur application on grain yield of millet, sorghum and maize have been determined by Friesen (1991), but no S-content has been reported for those experiments. Reported S recovery values are 0.05 for millet, 0.17 for sorghum and 0.08 for maize.

3. NUTRIENT REQUIREMENTS CALCULATION PROCEDURE (NUREQ)

3.1 Introduction

The nutrient requirements calculation procedure (NUREQ) calculates annual fertilizer or manure requirements in a target-oriented way, i.e. on the basis of exogenously determined target yields. As in some production techniques neither of these inputs is applied, fallowing is used as a practice to maintain soil fertility.

The calculations are based on the dynamics of nutrients within the production system (Figure 3.1). The figure shows, starting on the right hand side the possible nutrient inputs for the soil. Nutrients from farmyard manure (no 6), from inorganic fertilizer (5) and from various natural sources: rain, dust, run-on, flooding by river, irrigation water and micro-organisms (4). In addition, nutrients become available through mineralization of soil organic matter (10). In the soil these nutrients are subject to various processes, i.e. uptake by the crop (1), loss by erosion and run-off (2) or loss

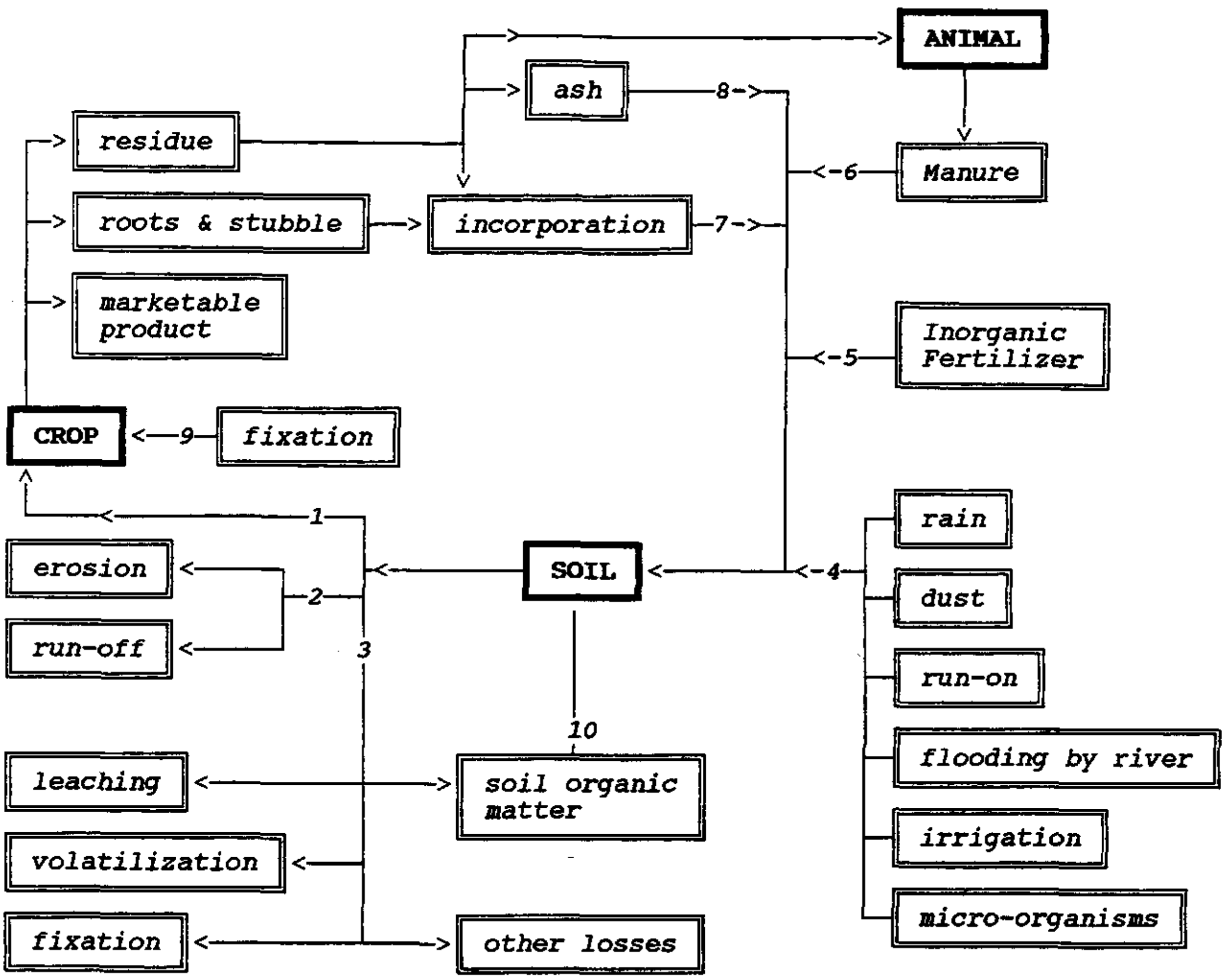


Figure 3.1. Schematized dynamics of macronutrients (nitrogen, phosphorus and potassium) in the production system.

through leaching, volatilization, irreversible fixation or incorporation in old soil organic matter (3). In legumes, N-fixation (9) contributes to the supply for the crop. The nutrients in the crop are partitioned among marketable product (thus completely exported from the field), root and stubble and crop residues. Nutrients from crop residues may partly be returned back to the field through the animal (6). Incorporation of biomass in the soil (7) and burning (8) are thus the last two sources of nutrient inputs.

Definition of sustainability in terms of nutrients implies that all nutrients taken up by the crop and lost from the system by surface runoff, erosion and other processes must be covered completely by inputs from natural sources and external sources. The procedure is restricted to nitrogen (N), phosphorus (P) and potassium (K). Unless indicated otherwise, yields and concentrations are on a dry weight basis.

Three cropping system intensities have been defined: *(i)* extensive, *(ii)* semi-intensive and *(iii)* intensive. Extensive refers to production techniques without any external inorganic fertilizer, intensive to techniques with high levels of such inputs and semi-intensive to intermediate levels. In addition, intensive systems include a high degree of innovative practices. Application of farmyard manure is considered extensive, because it refers to transfer of fertility within a given area. Fallowing can be interpreted as transferring arable fields towards surrounding pastures and manure application as transferring fertility towards arable fields by exploitation of the surrounding pasture by animals (Quilfen & Milleville, 1983; Tourte, 1963).

The calculation procedure, actually performed with a spreadsheet (EXCEL), consists of the following steps. First, relevant soil types are characterized and subsequently target yield and biomass distribution among the principal plant organs are defined in relation to soil type. Multiplying the biomass components with their respective nutrient concentrations results in the required content, i.e. total nutrient uptake. Subsequently, the various sources of the nutrients are quantified and finally the required amount of farmyard manure and/or inorganic fertilizer or the length of the fallow period is calculated.

3.2 Soil characterization

In the present study 15 soil types as presented in Table 3.1 have been distinguished.

As illustrated in Figure 3.1, various processes play a role in soil nutrient cycles. The first process that have to be quantified is that of soil erosion and runon-runoff. Erosion losses may be considerable under certain conditions (Stoorvogel & Smaling, 1990), but for the definition of sustainable production systems this type of losses should be reduced by all possible methods (e.g. terracing, planting of trees and tall grasses). For detailed information about these measures, reference is made to e.g. Rochette (1989). For the Fifth Region of Mali, losses due to erosion and run-off, and inputs by run-on and dust have been neglected under the assumption that they compensate each other.

Subsequently, processes involved in the nutrient cycles in the soil system have to be quantified. To derive the required amount of fertilizer from crop nutrient requirements, the recovery fraction must be established. The recovery fraction (REC) is defined as:

$$REC = (CONf - CON0) / APP \qquad (1)$$

where,

CONf = Nutrient content in crop at maturity following fertilizer application [kg ha^{-1}];
CON0 = Nutrient content in crop without fertilizer application [kg ha^{-1}];
APP = Amount of fertilizer applied [kg ha^{-1}].

Table 3.1. *Characterization of distinguished soil types in the Fifth Region of Mali.*

Soil type	Texture class		Available water capacity	Natural fertility
	surface	subsurface		
A	sand	sand	very low	low
B	loamy sand	loamy sand	low	low
C1	loamy sand, sandy loam	sandy loam, loam	moderate	medium
C2	sandy loam	gravelly sandy loam, clay loam	very low - low	low - medium
D1	sandy loam, loamy sand	sandy clay, loam	moderate	medium - high
D2	sandy loam,	sandy clay, loam	moderate	low
E1a	clay loam, silt loam	silty clay loam	high - very high	very high
E1b	silt loam	silty clay, loam	high	high
E2a	loam, silty clay loam	silty clay loam	high	medium
E2b	silt loam	silty clay	high	medium
F1	sandy loam, silty loam, silty clay	clay loam	medium - high	medium - low
F2	gravelly loam, loam, sandy loam	gravelly loam-clay, clay, clayey loam	very low	low - medium
F3a	sandy loam	clay loam	high	medium - high
F3b	silt loam	clay loam	very high	high
G	loamy & sandy, coarse loamy	fine loamy, stratefied alluvium	moderate	medium -low

Source: Cissé & Gosseye, 1990.

In situations where detailed results of fertilizer experiments are lacking, the recovery fraction has to be estimated on the basis of an assumed distribution of the applied N, P and K among the various processes illustrated in Figure 3.1 (3). It is assumed that the behaviour of nutrients in the soil is independent of their source (Section 3.4). The estimated distribution applies to an equilibrium situation. For phosphurus in this situation, the amount of residual phosphorus also becomes available for plant uptake. Hence, the fractions 'residual' and 'plant uptake' are summed in the calculations. If soil improvement in terms of nutrient availability (from actual to equilibrium situation) has to be quantified, the partitioning may change considerably.

For the Fifth Region of Mali, the distribution has been assessed for each combination of soil type and nutrient for both rainfed and irrigated situations (Tables 3.2 and 3.3, respectively). For instance, for nitrogen applied to soil type B1 (loamy sand), the partitioning is: incorporation in soil organic matter 0.3, leaching 0.15, volatilization 0.15, denitrification 0.10 and hence apparent recovery (plant uptake) 0.30. Because of limited information on the actual soil fertility status of the various soils, no distinction has been made between the four distinguished rainfall zones (Cissé & Gosseye, 1990).

Table 3.2. *Distribution of nitrogen, phosphorus and potassium among the various processes for the various soil types of the Fifth region of Mali, as applied for rainfed crops.*

PROCESS	SOIL TYPE A	B1	B2	C1,2	D1	D2
NITROGEN						
Incorporation	0.30	0.30	0.30	0.35	0.25	0.20
Leaching	0.25	0.15	0.15	0.10	0.10	0.10
Volatilization	0.15	0.05	0.15	0.10	0.05	0.05
Denitrification	0.00	0.10	0.10	0.10	0.15	0.15
Plant uptake	0.30	0.40	0.30	0.35	0.45	0.50
PHOSPHORUS						
Incorporation	0.30	0.30	0.30	0.35	0.25	0.25
Fixation	0.30	0.30	0.30	0.35	0.30	0.40
Residual	0.20	0.20	0.20	0.15	0.20	0.20
Plant uptake	0.20	0.20	0.20	0.15	0.25	0.15
POTASSIUM						
Incorporation	0.15	0.15	0.15	0.20	0.20	0.20
Leaching	0.20	0.20	0.20	0.10	0.10	0.10
Fixation	0.15	0.15	0.15	0.10	0.10	0.10
Plant uptake	0.50	0.50	0.50	0.60	0.60	0.60

	E1	E2	F1	F3	G
NITROGEN					
Incorporation	0.30	0.20	0.30	0.35	0.40
Leaching	0.10	0.20	0.10	0.10	0.05
Volatilization	0.10	0.20	0.05	0.05	0.05
Denitrification	0.20	0.20	0.25	0.25	0.30
Plant uptake	0.30	0.20	0.30	0.25	0.20
PHOSPHORUS					
Incorporation	0.30	0.20	0.30	0.30	0.35
Fixation	0.25	0.45	0.30	0.30	0.30
Residual	0.15	0.15	0.15	0.15	0.20
Plant uptake	0.30	0.20	0.25	0.25	0.15
POTASSIUM					
Incorporation	0.20	0.15	0.20	0.20	0.25
Leaching	0.10	0.15	0.10	0.10	0.10
Fixation	0.05	0.10	0.05	0.05	0.10
Plant uptake	0.65	0.60	0.65	0.65	0.55

Table 3.3. Distribution of nitrogen among the various processes for irrigated rice cultivation. For phosphorus and potassium, see Table 3.2.

PROCESS	SOIL TYPE E1	E2	F3
NITROGEN			
Incorporation	0.30	0.25	0.35
Leaching	0.05	0.10	0.05
Volatilization	0.05	0.10	0.00
Denitrification	0.35	0.35	0.40
Plant uptake	0.25	0.20	0.20

Compared to world-wide average values (Section 2.6), relatively low recovery fraction values are assumed for this region, but the former have generally been obtained under experimental conditions and not in farmers fields. In addition, the fraction of fertilizer incorporated in soil organic matter is set relatively high as at present, fertilizer application in sub-Saharan Africa is very limited (Bumb, 1991; Vlek, 1990). It is likely that this fraction will decrease gradually in the course of time as observed in the Netherlands (van der Meer & van Uum-van Lohuyzen, 1986). Also Wolf *et al.* (1987) have demonstrated that the recovery increases following continuous fertilizer application, and consequently, the recommended fertilizer rates have to decrease. As this will take its time, conservative values are used to avoid too much optimism.

3.3 Crop nutrient content

Total content of N, P and K at maturity for each production technique is calculated as the product of biomass of marketable product and crop residues (including roots and stubble) and their respective concentrations at harvest.

Target yields were defined per agro-ecological zone, each characterized by more or less homogeneous conditions with respect to rainfall and soil characteristics.

Potential yields (attainable under optimum supply of water and nutrients, and in the absence of weeds, pests and diseases) and yields under water-limiting conditions can be obtained from simulation models (e.g. Erenstein, 1990; van Keulen & Seligman, 1987; Penning de Vries *et al.*, 1989). In actual practice, however, yield may be limited by either water or nutrient shortages at different periods during the growth cycle and due to pests and diseases. Fore these situations, yields from farmers fields have been used as target yields.

Total aboveground biomass has been calculated from simulation models for millet, sorghum and cowpea as function of soil type (Table 3.1) and climatological conditions and their crop specific characteristics. It appeared from these results that crop residue production depends on crop production technique, soil type and rainfall. Simulated crop residue production was plotted against simulated grain yield for normal and dry years over the 30-year period for each soil type in rainfall zone I (Cissé & Gosseye, 1990), as illustrated for millet, sorghum and cowpea in Figure 5.2, 6.1 and 12.1, respectively. Subsequently, for each target yield of an activity (i.e. for all other rainfall zones), crop residue production was derived from that curve. As in the MGLP-model only linear relations can be included, a linear regression line has been calculated relating crop residue production to target yield (Straw = a * target yield + c). Hence, in the output-table of cropping systems crop residue production has both a yield-dependent and an area-dependent component.

However, these regression lines can not be applied for the extensive and semi-intensive techniques, as the harvest indices (ratio of yield to total aboveground biomass production) are generally higher (Donald & Hamblin, 1976). As pertinent information was not available, the regression lines have been adapted on the basis of common insight, such that the intercept with the yield axis (c) was lower and the slope of the line (a) somewhat steeper for yields up to 900 kg ha^{-1} (Table 3.4).

An alternative approach is based on the generalized harvest indices (Subsection 2.3.1), which has been used for fonio and rice. Also for groundnut, generalized dry matter distribution data have been used.

The weight of roots and stubble has been calculated on the basis of shoot-root ratio's, defined as a function of crop and system intensity. For cereals these values have been set at 4, 4 and 6 for the extensive, semi-intensive and intensive technique, respectively, and for leguminous species at 5, 5 and 7.

Table 3.4. *Straw yield [S, kg ha^{-1}] as function of yield [Yt, kg ha^{-1}] for millet, sorghum and cowpea activities.*

CROP	SOIL	TECHNIQUE EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Millet	B1	S = 600 + 4.3*Yt	S = 600 + 4.3*Yt	S = 2.7*Yt
	B2	S = 600 + 4.3*Yt	S = 600 + 4.3*Yt	S = 3300 + 1.3*Yt
	C1	S = 600 + 2.3*Yt	S = 600 + 2.3*Yt	S = 1700 + 1.2*Yt
	C2	S = 600 + 3.7*Yt	S = 600 + 3.7*Yt	-
	D1	S = 300 + 3.0*Yt	S = 300 + 3.0*Yt	-
	E1a	S = 100 + 2.7*Yt	-	-
	E2a	S = 80 + 2.8*Yt	-	-
	F1	S = 200 + 3.5*Yt	S = 200 + 3.5*Yt	S = 1830 + 1.3*Yt
Sorghum	E1,E2		S = 3480 + 0.42*Yt	
	G		S = 4310 + 0.41*Yt	
Cowpea	B2		S = 300 + 3.0*Yt	S = 1700 + 1.3*Yt
	C1		S = 200 + 2.0*Yt	S = 770 + 1.2*Yt
	C2		S = 300 + 2.8*Yt	.
	D1		S = 90 + 2.9*Yt	.
	F1		S = 50 + 2.7*Yt	S = 700 + 1.7*Yt

Source: Figures 5.2, 6.1 and 12.1.

Minimum concentrations in the major crop components are given in Table 2.6. However, nutrients are practically never diluted to these minimum concentrations due to negative effects of other yield-limiting factors. To take this phenomenon into account, a multiplier has been introduced defined as a function of system intensity, which has been has been set at 1.2 and 1.3 for grain and straw, respectively for extensive and semi-intensive systems. For intensive systems, these values are 1.4 and 1.7, respectively. Because of the low number of observations for onions and 'other vegetables' (van Duivenbooden *et al.*, 1991), no multiplier has been applied for these crops.

3.4 Sources of N, P and K

It is assumed that the behaviour of nutrients in the soil is independent of their source (inorganic fertilizer, manure, crop residues). Evidence for this assumption is scarce. For instance, nutrient N and P losses in farmyard manure and straw burried in the soil during the growing season in Senegal, amounted to 30-35% of original N-content and for P about 70% in both materials (van Duivenbooden & Cissé, 1989). In Niger, millet residues were applied as surface mulch and after five years, millet yields were comparable those with inorganic fertilizer application (at a rate of 30 kg N and 13 kg P per ha; Geiger *et al.*, 1992). Furthermore, they measured available-P in the surface 20 cm. In the plot with mulch and P-fertilizer it was equal to that in the plot with mulch plus the one with P-fertilizer, but as mulch also acts through entrapment of eolian materials and stabilizing the original soil (resulting in a higher surface of 15-20 cm when compared with the control plots) distinction between the various P-sources is difficult.

3.4.1 Nutrient availability from natural sources

In addition to nutrients originating from mineralization during decomposition of old soil organic matter (Figure 3.1, 10), nutrients from other natural sources are available, such as rain, dust, irrigation water, river water in flood-retreat crops and micro-organisms (free living bacteria; 4). Hence, all these processes have to be quantified.

Data on availability from natural sources can be derived from fertilizer experiments, if they are carried out and analysed properly. This implies that nutrient content has also been determined as discussed in detail by van Keulen (1982) and Siband *et al.* (1989). Consequently the results can be evaluated by means of the three quadrant figures (Figure 2.1).

3.4.1.1 Natural soil fertility

Natural soil fertility is defined as the total amount of a nutrient mineralized from the stable organic matter and originating from weathering processes in the course of the growing season.

A method to obtain the supply from natural sources, is following the QUEFTS-system (Janssen *et al.*, 1990) based on soil chemical characteristics.

However, in the absence of independent data on natural soil fertility or on soil chemical characteristics (as in this study), natural soil fertility can be defined as the ratio of the required uptake of the nutrient to the fraction of the fertilizer allocated to soil organic matter. In other words, the amount of fertilizer nutrients incorporated in stable soil organic material is identical to the amount mineralized from that source. This follows from the assumption of an equilibrium situation.

3.4.1.2 Rain and dust

The amount of nitrogen in rainwater for the West African situation is estimated at 0.0065 kg ha^{-1} mm^{-1} (Krul *et al.*, 1982), that of phosphorus and potassium at 0.0007 and 0.005 kg ha^{-1} mm^{-1}, respectively (Piéri, 1979). Although dust deposition may amount to about 1 500 kg ha^{-1} yr^{-1} (Wilding *et al.*, 1989), the variability of deposition in space and time and in composition of dust is considered too large and the absolute quantity too low to take dust into account as a separate input.

On the basis of precipitation for 'normal' years (Veeneklaas *et al.*, 1991) in rainfall zones I to IV of 531, 457, 376, and 255 mm, respectively, and for 'dry' years of 363, 302, 237 and 153 mm, respectively, the inputs of N, P and K are calculated.

3.4.1.3 Irrigation water

As no quantitative data are available for the situation in the Fifth region of Mali, the amount of N, P and K is estimated on the basis of those in rainwater at 0.005, 0.0005 and 0.01 kg ha^{-1} mm^{-1}, respectively.

CRD (1986) estimates the quantity of irrigation water for the rainy and dry season at 13 000 and 25 000 m^3 ha^{-1}, respectively. The former seems low at an average consumption of rice of 8 mm d^{-1} (RFMC, 1980) and a simulated evaporation loss of about 800 mm (Erenstein, 1990). The latter seems relatively high, taking into account identical transpiration rates, but an evaporation of 900 mm. In this study the quantity of irrigation water for the rainy and the dry season has been set at 18 500 and 19 500 m^3 ha^{-1}, respectively to calculate the inputs of N, P and K.

3.4.1.4 River water

River water is only available in the fifth Region of Mali for flood-retreat sorghum and (outside-)polder rice cropping systems (van Duivenbooden *et al.*, 1991). The amount of nitrogen supplied by river water is estimated at 6 to 9 kg ha^{-1} (Breman, pers. comm.), a value of 8 kg ha^{-1} being applied in the calculation method.

The amount of phosphorus supplied by river water has been set arbitrarily at 10 % of that of nitrogen, i.e. 0.8 kg ha^{-1}, and that of potassium at 5 kg ha^{-1}.

3.4.1.5 Associated bacteria

Nitrogen-fixing bacteria associated with plant roots produce about 0.0001 kg N per kg DM produced under West African conditions, whereas phosphorus production is one tenth of that, thus 0.01 g kg^{-1} (Krul *et al.*, 1982).

3.4.1.6 Free living bacteria

The contribution to N and P supply from free living bacteria associated with organic matter incorporated in the soil is estimated under West African conditions at 0.00025 and 0.000025 kg kg^{-1} DM incorporated, respectively (Krul *et al.*, 1982).

3.4.2 Nutrients available from crop residues

Crop residues, and hence nutrients, from last year's crop are returned to the soil *(i)* through animals, i.e. as manure (Figure 3.1, 6), *(ii)* by incorporation (7), *(iii)* in the form of ash (8). Furthermore, nutrients are returned to the soil complex by micro-organisms associated with dead roots.

In the calculation procedure two forms are distinguished: roots, stubble and associated micro-organisms, and straw left in the field, partly as such and partly as ash. It is assumed that the amounts of nutrients incorporated in roots and stubble are identical each year.

3.4.3 Nutrients available from the crop

Nitrogen can be fixed symbiotically by some crops (groundnut, bambara groundnut and cowpea) (Figure 3.1, 9), thus reducing the input requirements. Although N_2-fixing bacteria also occur on cereal substrates (Bley *et al.*, quoted by Geiger *et al.*, 1992; Christiansen-Weniger *et al.*, 1985), that possiblity has been omitted in this study.

The fraction of 'self-sufficiency' for legumes has been set at 0.7 for these species, based on data from literature (Tables 11.5 and 12.5 for groundnut and cowpea, respectively).

In addition, it has been assumed that for these species only 80% of total N is harvested and that the remainder is left in the soil (roots and shedded leaf blades).

3.5 Fertilizer and manure requirements

3.5.1 External N, P and K requirements

The external requirements to achieve the target yields for each nutrient are, on the basis of Equation 1, calculated separately by:

REQ = (CONf - FIX - CON0) / REC (2)

where,
REQ = External nutrient requirement [kg ha^{-1}];
CONf = Nutrient content in crop at maturity following fertilizer application [kg ha^{-1}];
FIX = Nitrogen fixation by crop; for P & K: 0 [kg ha^{-1}];
CON0 = Nutrient content in crop at maturity without fertilizer application [kg ha^{-1}];
REC = Apparent recovery for nutrient e [-].

In the absence of data on nutrient content at different fertilizer rates, it becomes:

REQ = ((CON - FIX) / REC) - NAT1 - NAT2 - CRR1 - CRR2 (3)

where,
NAT1 = Natural nutrient soil fertility [kg ha^{-1}];
NAT2 = Nutrient availability from additional natural resources [kg ha^{-1}];
CRR1 = Nutrient availability originating from crop's roots and stubble of preceding year [kg ha^{-1}];
CRR2 = Nutrient availability originating from crop's straw and ash of preceding year [kg ha^{-1}];

In the following, Equation 3 is further applied. In the equilibrium situation, the amount of nutrients incorporated in soil organic matter equals the amount released from soil organic matter (Paragraph 3.4.1.1):

NAT1 = FOM * (CON - FIX) / REC (4)

where,
FOM = Fraction of nutrient applied incorporated in stable soil organic matter [-].

Hence, Equation 3 can be rewritten as:

REQ = ((CON - FIX) * (1 - FOM) / REC) - NAT2 - CRR1 - CRR2 (5)

3.5.2 Farmyard manure and inorganic fertilizer requirements

Availability of nutrients from applied farmyard (organic) manure for plant uptake depends on its rate of decomposition and its quality. These two characteristics are interrelated, but the actual quantitative relationships are poorly understood, and need more research as discussed by de Ridder & van Keulen (1990).

The quality of farmyard manure, defined in general terms of absolute and relative nutrient content, is a function of the type of animal, the quality of its diet, the way of conservation and the time between excretion and application in the field.

For definition of a generally applicable value, the 50% probability level of nutrient concentration as calculated from the available West African data (Table A3.1, Annex 3) has been used, i.e. 12.7, 2.8 and 13.0 g kg^{-1} on DM basis for N, P and K, respectively.

The fraction of the total nutrient requirements to be met by manure depends on both crop and system intensity. For all production techniques, except when fallowing is practiced (with manure dropped in the field included), organic manure is required, as application of inorganic fertilizer only will result in a decrease in soil organic matter and nitrogen (e.g. Wolf *et al.*, 1989). In addition, presence of organic materials in the soil leads to higher exchangeable kations and enhanced root growth, as observed with applied crop residues in Niger (Kretzschmar *et al.*, 1991).

On the other hand, application of manure depends on crop type. For instance, cowpea tolerates manure application, so that it has been assumed that in extensive systems and intensive systems nutrient requirements are covered for 50 and 20%, respectively by manure and the remainder by inorganic fertilizer.

The amount of manure required is calculated for N, P and K separately:

$$MAN = REQ * FMM / CONC \qquad (6)$$

where,
MAN = Manure requirements [kg ha^{-1}];
FMM = Fraction of the total nutrient requirements covered by manure [-];
CONC = Concentration of nutrient e in manure [kg kg^{-1}].

In defining the production technique, the maximum of the three calculated values of manure requirements (MAN_m) is used. If FMM is less than one, the remainder of the total nutrient requirements is covered by inorganic (chemical) fertilizer:

$$FER = REQ - (MAN_m * CONC) \qquad (7)$$

where,
FER = Inorganic fertilizer requirements for nutrient e [kg ha^{-1}];
MAN = Manure application rate for the production technique [kg ha^{-1}].

3.6 Ratio fallow years/year of cultivation

Where external inputs of nutrients are not applied, cropping may be feasible by intermittent exploitation of accumulated nutrients from the various natural sources, i.e. fallowing.

The fraction of the vegetation not consumed by animals during fallow periods contributes to inputs of nutrients into the soil. In the calculation procedure, that contribution has been estimated on the basis of an equilibrium situation (sustainability in terms of nutrients). Inputs through rain, fixation by leguminous species and algae have been taken into account. Algae are assumed to be active under fallow only and not after ploughing. Wolf *et al.* (1989) have derived a relation on the net input of nitrogen during fallowing in temperate regions,-but for sub-Saharan Africa the equation derived by de Wit & Krul (1982) is applied:

$$N_b = (0.0085 * PR) / (1.025 * F - (0.02 * L + 0.038)) \quad (8)$$

where,

N_b = Total amount of nitrogen in aboveground biomass [kg ha^{-1}];
PR = Precipitation [mm];
F = Fraction of N lost from the vegetation [-];
L = Proportion of leguminous species in the vegetation [kg kg^{-1}].

It has been estimated that in natural pastures under sub-Saharan conditions (in the equilibrium situation), a fraction of 0.3 to 0.5 of the peak amount of nitrogen in the biomass is lost each year, e.g. by grazing and volatilization (Breman, 1991). For fallow fields the grazing pressure is assumed to be half of that of natural pastures, and taking into account some selective grazing behaviour, a value for F of 0.3 has been used. Furthermore, the contribution of leguminous species has been estimated at 5% on a DM basis. Hence, the N_b-formula reduces to:

$$N_b = (0.0085 * PR) / 0.1695 \quad (9)$$

In that situation, the amount of nitrogen lost annually (N_e) is thus:

$$N_e = F * N_b \quad (10)$$

For sustainable systems, this amount should at least be covered by input of N under fallow. Quantitative data on these processes are scarce, and published evidence is ambiguous: net input slightly positive (Stoorvogel & Smaling, 1990; Poulain, 1980) or negative (van de Pol, 1992). At clearing after fallow, trees and shrubs are removed from the field, with its associated consequences for the N, P and K balances. In the calculation procedure, the net annual input during fallow (FI) has been set at 1.3 times the amount of nutrients lost (N_e).

Substitution of the value 0.3 for F in Equation 10 and combining with Equation 9, results for nitrogen in:

$$FI_N = 0.020 * PR \quad (11)$$

where,

FI_N = Net amount of nitrogen added to the soil [kg ha^{-1}].

This implies for a fallow field in an agro-ecological zone with 541 mm rainfall on average, a net annual nitrogen input of 10.8 kg ha^{-1}, i.e. similar to the net input calculated on the basis of 5 times a millet crop (yield 500 kg ha^{-1}) and a 20 year fallow period.

In the calculation procedure, the amounts of phosphorus and potassium added to the soil system have been estimated at 0.12 and 1.0 time those of nitrogen, respectively. These estimates are based on limited evidence, and more research is needed to substantiate them.

As the equations hold for an equilibrium situation, where losses and contributions from natural sources implicitly have been taken into account, the required duration of the fallow period per year of cultivation has been calculated separately for each nutrient:

$$YFYC = (((CON - FIX) / REC) - CRR1) * (1/FI) \quad (12)$$

where,
YFYC = Years of fallow per year of cultivation [-];
FI = Annual nutrient input during fallow [kg ha^{-1}].

Comparing the lengths of the fallow periods required to meet the requirements for N, P and K, it is clear that the required length is determined by P-input. That period is generally twice as long as the one based on equilibrium for nitrogen. This supports the general conclusion from research carried out in Mali (Penning de Vries & Djitèye, 1982), that in the northern areas phosphorus is more rapidly depleted than nitrogen.

In the description of the production techniques, the maximum of the three values is used. For some crops (e.g. fonio and groundnut), the required length of the fallow period was strongly dictated by the phosphorus balance. As the length of the fallow period could be reduced substantially by a small input of chemical P-fertilizer, this practice was included in the description of the production techniques (van Duivenbooden *et al.*, 1991).

An example of the application of this calculation procedure for two millet activities in the Fifth Region of Mali is presented in Table 3.5, with the detailed calculation procedure in Table 3.6.

Table 3.5. *Illustration of application of NUREQ for calculating fertilizer/manure requirements and ratio of fallow years per year of cultivation for two millet activities (i1 & i6) on a B1 soil in the wettest rainfall zone I in the Fifth Region of Mali.*

PARAMETER	UNIT	VALUE		
Target yield	[kg ha^{-1}]	500		
Straw yield	[kg ha^{-1}]	2750		
Total	[kg ha^{-1}]	3250		
shoot-root ratio	[-]	4		
Roots & stubble	[kg ha^{-1}]	813		
fraction straw left in the field	[-]	0.30		
fraction straw burnt	[-]	0.50		
Straw buried in soil	[kg ha^{-1}]	1225		
UPTAKE REQUIREMENTS		N	P	K
Minimum concentration grain	[g kg^{-1}]	13.0	1.8	10.0
Minimum concentration straw	[g kg^{-1}]	3.0	0.3	4.0
multiplier grain	[-]	1.2	1.2	1.2
multiplier straw	[-]	1.3	1.3	1.3
content above-ground DM	[kg ha^{-1}]	18.5	2.15	20.3
content roots & stubble	[kg ha^{-1}]	3.2	0.32	4.2
Total content	[kg ha^{-1}]	21.7	2.47	24.5
SUPPLY FROM NATURAL SOURCES				
rain water	[kg ha^{-1}]	3.5	0.37	2.7
river water	[kg ha^{-1}]	0.0	0.00	0.0
irrigation water	[kg ha^{-1}]	0.0	0.00	0.0
micro-organisms org. mat.	[kg ha^{-1}]	0.3	0.03	0.0
SUPPLY FROM CROP RESIDUES				
roots & stubble	[kg ha^{-1}]	3.2	0.32	4.2
micro-organisms roots	[kg ha^{-1}]	0.3	0.03	0.0
straw left in the field	[kg ha^{-1}]	1.2	0.12	1.7
ash from straw	[kg ha^{-1}]	0.5	0.10	1.0
NUTRIENT REQUIREMENTS				
Recovery fraction	[-]	0.40	0.40	0.50
Fraction of nutrients to soil organic matter	[-]	0.30	0.30	0.15
nutrient requirements	[kg ha^{-1}]	29.0	3.38	32.2
MANURE REQUIREMENTS (i1)				
Fraction requirements met by farmyard manure	[-]	1.0	1.0	1.0
Manure requirements	[kg ha^{-1}]	2282	1206	2475
Requirements applied in MGLP-model	[kg ha^{-1}]	2480		
FALLOW/CULTIVATION (i6)				
Input from fallow	[kg ha^{-1}]	10.6	1.3	10.6
Ratio fallow years/year cultivated	[-]	4.8	4.6	4.2
Ratio used	[-]	5		

Table 3.6. Calculation scheme of NUREQ.

	A	B
1	ACTIVITY	i1/i6
2	Crop	millet
3	System intensity	extensive
4	Soil	B1
5	Zone	I
6	Precipitation (mm)	531
7	Irrigation (mm)	0
8		
9	FIELD DATA	
10	Net yield	400
11	Target yield (Yt)	=1.25*B10
12	Straw	=600+4.3*B11
13	Total	=B11+B12
14	Shoot-root ratio	4
15	Root + stubble	=B13/B14
16	fraction straw on field	0.2
17	fraction straw burnt	0.5
18	OM buried in soil	=B15+(B12*B16*(1-B17))
19	straw/target	=B12/B11
20	S= a+b*Yt	600+4.3Yt
21		
22	N-requirement:	
23	N%min-grain	1.3
24	N%min-straw	0.3
25	multiplier N%grain	1.2
26	multiplier N%straw	1.3
27	Nu (tagb)	=(B11*B23*B25/100)+(B12*B24*B26/100)
28	uptake roots+ stub.	=B15*B24*B26/100
29	N-UPTAKE TOTAL	=B28+B27
30	recovery N	0.4
31	Nu/RFN	=B29/B30
32		
33	N-natural sources	
34	N-rain water	=B6*0.0065
35	N-root+stubble	=B28
36	N-micro-roots	=0.0001*B13
37	N-micro-buried OM	=0.00025*B18
38	N-straw left on field	=(1-B17)*B16*B12*B24/100
39	N-straw -ashes	=0.4*B17*B16*B12*B24/100
40	N-fraction org. matter	0.3
41	N-soil fertility	=B31*B40
42	N-NAT. SOURCES	=SUM(B34:B39)+B41
43		
44	N-REQUIRED	=B31-B42
45		
46	P-requirement:	
47	P%min-grain	0.18
48	P%min-straw	0.03
49	multiplier P%grain	=B25
50	multiplier P%straw	=B26
51	Pu (tagb)	=(B11*B47*B49/100)+(B12*B48*B50/100)
52	uptake roots+ stub.	=B15*B48*B50/100
53	P-UPTAKE TOTAL	=B52+B51
54	recovery P	0.4
55	Pu/RFP	=B53/B54
56		
57	P-natural sources	
58	P-rain water	=B6*0.0007
59	P-roots+stubble	=B15*B48*B50/100
60	P-micro-roots	=0.00001*B13
61	P-micro-buried OM	=0.000025*B18
62	P-straw left on field	=B12*B16*(1-B17)*B48/100
63	P-straw -ashes	=0.8*B17*B16*B12*B48/100
64	P-fraction org. matter	0.3
65	P-soil fertility	=B55*B64
66	P-NAT. SOURCES	=SUM(B58:B63)+B65
67		
68	P-REQUIRED	=B55-B66
69		
70	K-requirement:	
71	K%min-grain	1
72	K%min-straw	0.4
73	multiplier K%grain	=B25
74	multiplier K%straw	=B26
75	Ku (tagb)	=(B11*B71*B73/100)+(B12*B72*B74/100)
76	uptake roots+ stub.	=B15*B72*B74/100
77	K-UPTAKE TOTAL	=B76+B75
78	RFK	0.5
79	Ku/RFK	=B77/B78
80		
81	K-natural sources	
82	K-rain water	=B6*0.005
83	K-roots+stubble	=B15*B74*B72/100
84	K-straw left on field	=(1-B17)*B16*B12*B72/100
85	K-straw -ashes	=0.6*B17*B16*B12*B72/100
86	K-fraction org. matter	0.15
87	K-soil fertility	=B79*B86
88	K-NAT.SOURCES	=B82+B83+B84+B85+B87
89		
90	K REQUIRED	=B79-B88
91		
92	REQUIREMENTS	
93	N	=B44
94	P	=B68
95	K	=B90
96	N req. 100 kg grain-1	=B93*100/B11
97	P-req. 100 kg grain-1	=B94*100/B11
98	K-req. 100 kg grain-1	=B95*100/B11
99	av N req. /100 kg	=AVERAGE(B96)
100	av P req. /100 kg	=AVERAGE(B97)
101	av P req. /100 kg	=AVERAGE(B98)
102		
103	MANURE	
104	N% manure	1.27
105	P% manure	0.28
106	K% manure	1.3
107	manure req. for N	=B93*100/B104
108	manure req. for P	=B94*100/B105
109	manure req. for K	=B95*100/B106
110	MANURE req. used	=MAX(B107;B108;B109)
111	manure / Yt	=B110/B11
112	av. MANURE/Yt	=AVERAGE(B111)
113		
114	FALLOW	
115	N-input fallow y-1	=B6*0.02
116	P-input fallow y-1	=0.12*B115
117	K-input fallow y-1	=B115
118	years fallow for N	=(B31-B35-B36)/B115
119	years fallow for P	=(B55-B59-B60)/B116
120	years fallow for K	=(B79-B83)/B117
121	Fallow used	=MAX(B118;B119;B120)
122	FALLOW USED	5

3.7 Discussion and conclusion

The nutrient requirements calculation procedure (NUREQ) enables us to make reasonable first estimates of nutrient requirements for sustainable agricultural production systems on the basis of limited data. However, the method can be improved, when more detailed information is available, e.g. by defining long term and short term nutrient pools as turn-over times differ for the various processes (quantification of nutrient availability in the course of the growing season). Then the procedure can be made 'dynamic'.

Another improvement of the procedure will be including the carbon balance. The role of manure application as compensation for the mineralization from that pool should be further investigated.

Also, the importance of other nutrients should be analyzed for certain production techniques. In some cases these nutrients may affect crop growth, e.g. sulphur in legumes. In addition, effects of nutrients on pH of the soil should be taken into account and effects of applied nutrients (Ca) to reduce the pH, as acidity of the soil determines partitioning of phosphorus.

Despite these shortcomings and constraints, the procedure represents a first attempt to describe sustainability in terms of nutrient balances. The procedure integrates at the moment knowledge of various disciplines and although it has been developed for the West African situation, it can easily be adapted for other parts of the world.

The implications of sustainability in terms of nutrients for agricultural production and the consequences for land use planning and agricultural development options for that region are described by Veeneklaas *et al.* (1991), van Duivenbooden *et al.* (1992) and in relation to food needs in the following chapter.

4. IMPACT OF INORGANIC FERTILIZER AVAILABILITY ON LAND USE AND AGRICULTURAL PRODUCTION IN THE FIFTH REGION OF MALI.

4.1 Introduction

Sound management of natural resources in agricultural production systems is necessary to maintain their productive capacity in the long run (van Keulen & Breman, 1990). In West Africa, the increasing population demands increasing food production, but land availability may form a constraint, especially when so-called traditional production techniques based on fallowing are practiced (Breman *et al.*, 1990; van Keulen & Breman, 1990). Often this problem is alleviated by reducing the length of fallow, with its associated consequences of nutrient mining and reduced yields (van de Pol, 1992; Reddy *et al.*, 1992).

To estimate the agricultural production potentials in a region under the condition of sustainable land use, an analysis is necessary that takes into account the region's natural and human resources and the available agricultural production techniques. Sustainability is defined as 'the successful management of resources for agriculture to satisfy changing human needs, without degrading the environment or the natural resource base on which agriculture depends' (TAC, 1989). Moreover, additional objectives of rural development with respect to risk avoidance, economic viability, etc. have to be considered. Such an analysis can be performed with a multi-criteria optimization method, as applied in the Interactive Multiple Goal Linear Programming model (IMGLP-model; de Wit *et al.*, 1988). This method was applied to the Fifth Region and the Cercle de Niafunké in Mali.

This chapter examines the possibilities of agricultural development of the region in relation to the policy goals to meet food needs and guarantee regional gross revenue, under the condition of sustainability.

Such an examination can be carried out in many ways, the one selected here is to analyse the impact of inorganic fertilizer availability (and its application) on land use, intensification level and degree of exploitation of natural resources.

At present, the use of inorganic fertilizer is limited, but with increased availability, the potential for increased agricultural production is more likely to be reached on the dominant low-fertility soils. Therefore, three development scenarios have been defined on the basis of inorganic fertilizer availability, the lowest level representing the actual situation and the highest level the potential situation. As objective, marketable crop production is maximized under the restriction of a minimum regional gross revenue, on the basis of sustainable agricultural production techniques.

4.1.1 The Fifth Region and the Cercle de Niafunké

The Fifth Region, including the Cercle de Niafunké, covers about 89 000 km^2 and is dominated by the central inland delta of the river Niger, an area of 16 000 km^2 which, under normal rainfall conditions, is flooded annually (Figure 4.1). This water resource in the heart of the Sahelian region offers opportunities for development of arable farming, animal husbandry and fisheries, far exceeding those in the surrounding area under rainfed conditions. However, over the past decades, increasing population pressure (about 1.3 million rural inhabitants or 18 persons km^{-2}), intermittent severe drought periods and breakdown of traditional land use regulations have resulted in increasing pressure on the land, conflicts among various groups of land users and disruption of the existing production systems. Moreover, production has often been insufficient to meet food needs, hence considerable food imports were required (Sijm, 1992; FEWS, 1992; IOV, 1991).

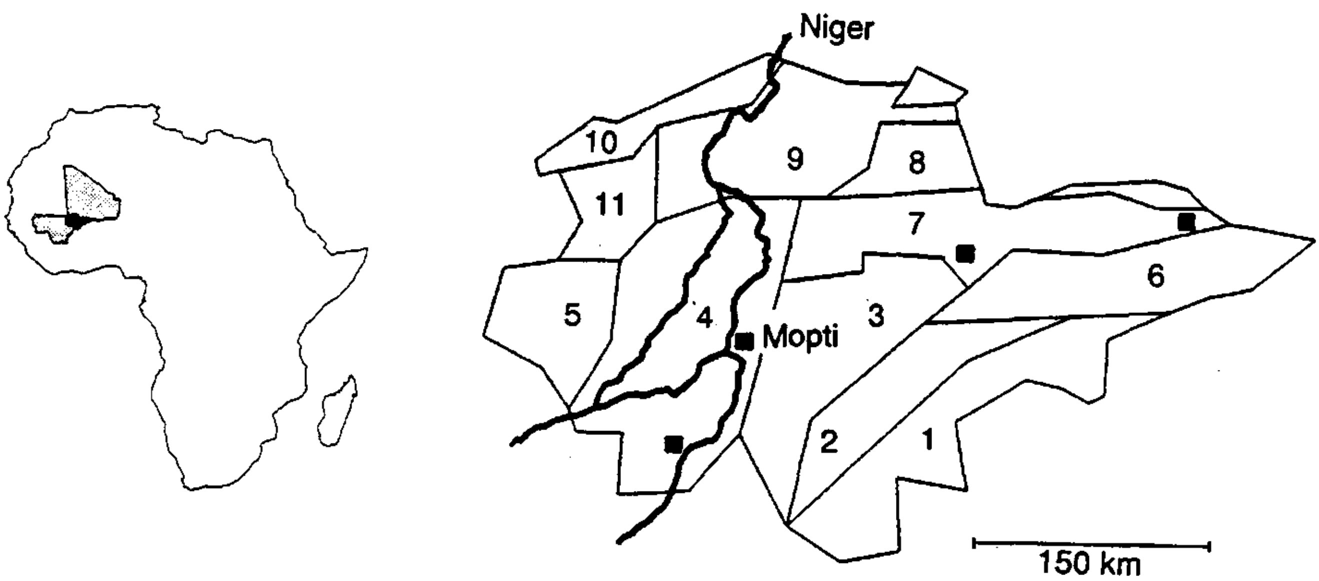


Figure 4.1. *Mali and the Fifth Region and Cercle de Niafunké. 1 = Sourou, 2 = Seno Bankass, 3 = Plateau, 4 = Delta Central, 5 = Mema Dioura, 6 = Seno Mango, 7 = Gourma, 8 = Bodara, 9 = Zone Lacustre, 10 = Hodh and 11 = Mema Sourango.*

To characterize the physical environment, combinations of soils, climate and natural vegetation were identified, resulting in eleven subregions, referred to as agro-ecological zones (Figure 4.1). To take into account rainfall variability, yields for various production techniques were defined for 'normal' and 'dry' rainfall regimes. On the basis of annual rainfall amount and distribution for the years 1959 to 1988 the 20% lowest values (6 years) were assumed to represent a dry year; and the 60% intermediate values (18 years) a normal year, in which average rainfall ranges from 257 mm in the north to 545 in the south (Table 4.1). The 20% highest values, representing a wet year, were not considered in the present study.

Table 4.1. *Average annual rainfall [mm yr^{-1}] and rainfall from May till October [mm] for dry, normal and wet years in the four rainfall zones, based on observations in the period 1959-1988 (Cissé & Gosseye, 1990).*

AGRO-ECOLOGICAL ZONE	MAY - OCTOBRE			ANNUAL		
	normal	dry	wet	normal	dry	wet
Rainfall Zone I						
Sourou & Séno Bankass	531	363	683	545	368	689
Rainfall Zone II						
Plateau & Delta Central	457	302	653	461	306	663
Rainfall Zone III						
Méma Dioura, Séno Mango & Gourma	376	237	502	379	237	512
Rainfall Zone IV						
Bodara, Zone Lacustre, Hodh & Méma Sourango	255	153	356	257	153	357

4.2 Methodology (with F.R. Veeneklaas)

4.2.1 General framework and definitions

Application of the IMGLP-method requires *(i)* formulation of an input-output table, describing in quantitative terms the possible activities, *(ii)* description of the relations among the various activities and the regional constraints, *(iii)* identification of a set of goal variables, representing the aspirations of the various interest groups, and *(iv)* a software package that can handle the multi-criteria decision method and solves the linear programming problem (i.e. SCICONIC; Scicon, 1986). Further details of the method used are given elsewhere (de Wit *et al.*, 1988; van Keulen & van de Ven, 1988; Spronk & Veeneklaas, 1983).

Three types of agricultural production systems are distinguished in the region, i.e. cropping systems, livestock systems and fishery systems (the latter are not further treated as they are not relevant in the context of this study). In each system various activities, i.e. well-defined production techniques with specific quantified inputs and outputs, have been defined at different intensity levels. For arable farming, the activity is related to soil type and crop species, and for animal husbandry to feed requirements and animal species.

Activities may take place in principle anywhere in the region, i.e. in any of the agro-ecological zones, unless specified otherwise (e.g. soil not suitable). They are defined on an annual basis in a target-oriented way, i.e. the production (output) per hectare or per animal is defined first and the requirements (inputs) to realize that production are derived subsequently, as illustrated below and treated in detail by van Duivenbooden *et al.* (1991).

4.2.2 Description of various relations

The relations between outputs and inputs (Figure 4.2) are governed by the quality of the natural resources and the production technique applied. The double-arrowed lines in Figure 4.2 indicate the alternative options for use of the natural resources, hence competition, of soil among the various land use categories, and labour among the different production sectors and work outside the region (physically or outside the agricultural sector, both referred to as emigration).

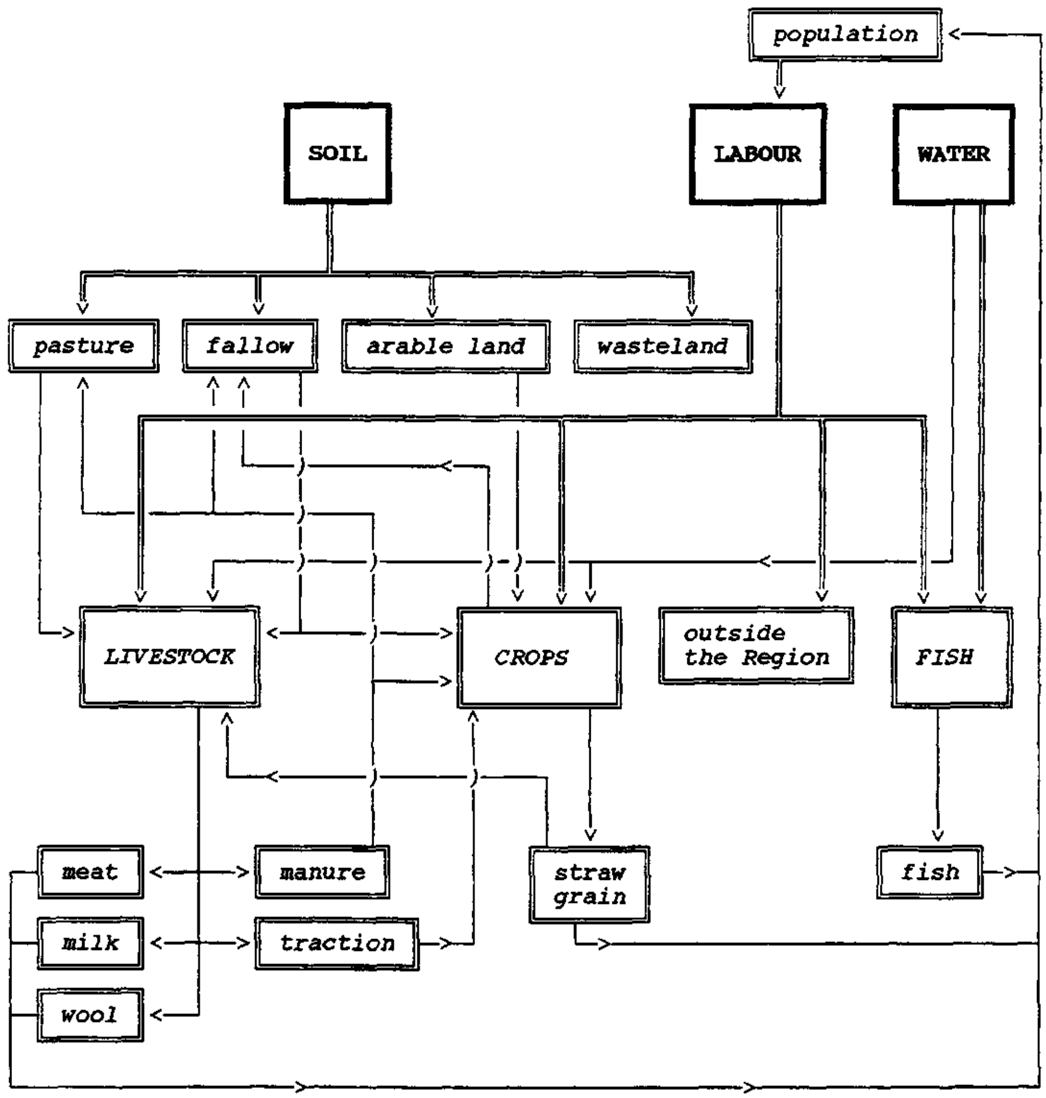


Figure 4.2. *General relations between natural and human resources (double lined) and inputs and outputs (single lined) in the agricultural production system. External inputs are not shown.*

The single-arrowed lines represent flows between production techniques. For instance, manure, produced in livestock systems can be used in arable farming and the remainder (not collected) is added to grazed fallow land or pasture, which in turn produce inputs for livestock systems.

At the basis of these relations were accurate descriptions of the natural resource base (soils, climate, natural vegetation) and the human resources, in terms relevant to the production techniques (Cissé & Gosseye, 1990). For a complete description of the relations in the model, reference is made to Veeneklaas (1990b).

4.2.3 Sustainability

To guarantee viable agricultural development in the long run, the production systems defined should be sustainable. Although sustainability comprises various aspects, for operational purposes only those aspects have been applied that could be quantified and incorporated in the IMGLP-model. For cropping techniques, sustainability was defined in terms of nutrient elements (Chapter 1). For livestock production techniques, sustainability referred to both primary and secondary production, under the conditions that stable herds can be maintained (total flock size in relation to fodder availability) and degradation of natural pasture is prevented (cf. Breman & de Ridder, 1991).

4.2.4 Subsistence needs

Subsistence needs, defined as the minimum amount of agricultural products required for consumption by the producers and their dependents, were specified per agro-ecological zone. This does not exclude trade of these products on local markets or exchange between producers; it simply implies that a certain minimum quantity is required per agro-ecological zone, either from local production or from imports. Emigrants (maximally 250 000) and inhabitants of Mopti-town (74 000) were excluded in calculating the subsistence requirements.

The subsistence needs in meat, grains and other crop products are set proportional to the number of inhabitants taking into account its age-structure (CRD, 1986) and includes three components:

1. **Animal protein intake;** minimum daily requirements (FAO/WHO, 1973) are, on average, met by 25 g meat (carcass weight) and 290 g milk per capita. The ratio milk/meat varied per agro-ecological zone, as milk production in the region is spatially variable;
2. **Energy intake;** minimum daily requirements, based on FAO/WHO (1973) and taking into account the energy content of proteins (940 kJ), are 7810 kJ per capita. These requirements were converted in millet-equivalents (cf. Mondot-Bernand, 1980), i.e. 626 g, and to may met by energy provided by millet and other crops (e.g. 1 kg of rice corresponds to 1.23 kg millet-equivalents);
3. **Variation in the diet of crop products;** it is safeguarded by setting minimum requirements on consumption of crop products other than millet, i.e. rice (10 kg), groundnut (5 kg), cowpea (2 kg), shallot (5 kg fresh weight) and other vegetables (15 kg fresh weight) all per year per capita.

4.2.5 Constraints

Constraints were defined per agro-ecological zone and concerned:

- Availability of soil (Figure 4.2). Sixteen soil types have been distinguished on the basis of their physical and chemical properties (Table 4.2). For each soil type a 'utility index', the fraction of land that can be exploited, has been established to take into account specific conditions that exclude agricultural use (e.g. severe degradation).
  Certain soils were excluded for cultivation of particular crops, for instance because of problems with waterlogging or absence of irrigation facilities (Table 4.2).
  Distance to permanent water points also determined the mode of exploitation: crops can be grown within a 6 km radius and animals can use the rangeland within a 15 km radius of that water point during the dry season, under the assumption that a permanent water point supplies enough water both for human needs and for the animals;
- Availability of labour (Figure 4.2). This was derived from the population size taking into account age, sex, and degree of participation. Required labour for each of the activities has been specified for six distinct periods of the year (i.e. the periods of ploughing and sowing, first weeding, all other operations until harvest of millet, harvest of millet, harvest of rice, and outside the growing season of rainfed crops), to take into account peak periods in labour demand;
- Availability of draught animals;
- Availability of animal manure;
- Availability of forage, comprising both natural pastures and crop residues, specified per season, location (distance to a permanent water point) and quality class;
- Availability of transport animals, as a function of population density.

In addition, socio-economic and institutional constraints play a role, of which only a limited number could be incorporated in the model. For instance, in view of the limited transport facilities, the production of fresh vegetables was restricted. Commercial sales of milk was restricted to Mopti-town, as only there a milk processing plant was present.

4.2.6 Goals

The goal variables should in principle cover all major interests in the region, so as to ensure that technical options for its development are kept as open as possible. Consultations have been held therefore with national, regional and local authorities and development agencies. Their goals, however, were sometimes difficult to translate in terms relevant to the model, hence choices had to be made.

In total, twenty goal variables have been formulated that potentially could serve as objectives. In practice, however, only nine have been used as such, while the others served to set pre-defined minimum or maximum values. The major objectives specified refer to:

- Physical production in a normal year, separately defined for products from arable farming and from animal husbandry;

Table 4.2. *Description of distinguished soil types in the Fifth Region of Mali and the corresponding recovery fractions of nitrogen, phosphorus and potassium (N, P and K).*

Soil type	Texture class		Available water capacity	Natural fertility	Recovery fraction		
	surface	subsurface			N	P	K
A	sand	sand	very low	low	(not cultivated)		
B1	loamy sand	loamy sand (acid)	low	low	0.40	0.20	0.50
B2	loamy sand	loamy sand	low	low	0.30	0.20	0.50
C1	loamy sand, sandy loam	sandy loam, loam	moderate	medium	0.35	0.15	0.60
C2	sandy loam	gravelly sandy loam, clay loam	very low - low	low - medium	0.35	0.15	0.60
D1	sandy loam, loamy sand	sandy clay, loam	moderate	medium - high	0.45	0.25	0.60
D2	sandy loam,	sandy clay, loam	moderate	low	(not cultivated)		
E1a	clay loam, silt loam	silty clay loam	high - very high	very high	0.30	0.30	0.65
E1b*	silt loam	silty clay, loam	high	high	0.25	0.30	0.65
E2a	loam, silty clay loam	silty clay loam	high	medium	0.20	0.20	0.60
E2b*	silt loam	silty clay	high	medium	0.20	0.20	0.60
F1	sandy loam, silty loam, silty clay	clay loam	medium - high	medium - low	0.30	0.25	0.65
F2	gravelly loam, loam,	gravelly loam-clay, clay	very low	low - medium	(not cultivated)		
F3a	sandy loam	clay loam	high	medium - high	(not cultivated)		
F3b*	silt loam	clay loam	very high	high	0.20	0.25	0.65
G	loamy & sandy, coarse loamy	fine loamy, stratefied alluvium	moderate	medium -low	0.20	0.15	0.55

*) denotes that soils are inundated during part of the year.

- Monetary goals, subdivided into regional monetary revenue (= value of total agricultural production - subsistence needs - monetary inputs + incoming money from emigrants), and monetary inputs in agricultural activities;
- Risks in a dry year, specified in terms of food self-sufficiency and number of animals at risk;
- Employment and emigration.

4.2.7 Scenarios

On the basis of the objectives for development of the region, and the main constraints and relations in the IMGLP-model, technically feasible scenarios for agricultural land use with their associated production and inputs can be generated. Each scenario is characterized by the goal variable optimized (maximized or minimized) and the set of restrictions imposed on the other goal variables and, of course subject to all restrictions included in the model.

The goal restrictions have been obtained through the interactive approach of the model. In the first cycle restrictions, reflecting a low level of aspiration with regard to the goals, have been selected. In this cycle the model has been run to optimize each goal separately, at the same time resulting in different values of the other goals. Thus worst and best values were obtained for each goal, representing the feasible solution space for that goal. The next step consists of selecting the goal with the worst value considered unacceptable and formulating a tighter constraint for that goal. Several such steps have been taken. In this way the feasible combinations of goal values can be explored until only one combination is left. However, generally the procedure will be stopped at an earlier stage, leaving a space encompassing acceptable values for all goals. Within this space any selected goal can still be maximized (or minimized).

In an earlier study, two scenarios were analyzed, characterized by maximization of regional gross revenue, under two sets of goal restrictions (Veeneklaas *et al.*, 1991). In the present study, marketable crop production is maximized under three sets of goal restrictions.

4.3 Basic data

4.3.1 Cropping systems

In the model three crop types, with respect to management, have been considered: rainfed crops, flood retreat crops and irrigated or inundated crops. These were further classified by crop species, i.e. millet, rice, sorghum, fonio, groundnut, cowpea, bourgou, shallot and 'other vegetables', comprising among others maize, tomatoes, tobacco, cassava and cabbage.

The production techniques have been defined on the basis of four criteria: *(i)* use of fallow periods, *(ii)* use of oxen traction, *(iii)* application of farmyard manure and *(iv)* application of inorganic fertilizer.

Additionally, three intensity levels were distinguished: extensive, semi-intensive and intensive. Extensive refers to techniques without application of inorganic fertilizers, their sustainability being warranted by fallowing or application of farmyard manure. Intensive techniques are based on high input levels of inorganic fertilizers and include innovative practices. Semi-intensive techniques refer to intermediate levels of external nutrient inputs. Vegetable growing is always considered intensive based on its high inputs of pesticides.

The degree of differentiation of cropping production techniques depends on the relative importance of a crop species. For millet as the main crop of the region, six techniques were distinguished, whereas for fonio (a minor crop) one technique was described only. Rice may be cultivated under irrigation (IR-rice), in polders (P-rice) or outside polders at the banks of the rivers Niger and Bani (OP-rice; Table 4.3).

Outputs of crop activities comprise main products and crop residues. The former include grain (in the case of cereals and leguminous species), shallots and other vegetables, and forage (in the case of fodder crops and bourgou cultivation). Target yields of main products in normal years were based on simulation results or on data collected in the region.

Simulation results have been used to derive target yields of intensive and semi-intensive production techniques of millet and cowpea and of flood-retreat sorghum (van Duivenbooden, 1991; Erenstein, 1990). The first step was the calculation of water-limited yields (i.e. yields determined by water availability only, the supply of nutrient elements assumed to be optimum), on the basis of soil characteristics (pF-curve) and rainfall records for the period 1959-1988 of seven meteorological stations in the region. As no quantitative information on runoff and runon for the study area was available, and assuming that on a regional scale of hundreds of km^2 the positive and negative effects compensate, all rain was supposed to infiltrate in the fields.

The assumption of optimum nutrient supply implies a high input of inorganic fertilizer, as the supply from natural sources only covers a small fraction of the demand. However, even under optimum nutrient supply, management failures (lack of timeliness) lead to yield reductions, implying waste of external inputs. Therefore, the target yields for intensive techniques in normal years have been set at 80% of the simulated water-limited yields and for semi-intensive techniques at 40% of those for the intensive techniques.

Target yields for extensive techniques have been derived from local data, as no simulation models exist yet that take into account the situation where alternating nutrient elements and water may be growth-limiting. The use of animal traction in extensive techniques was estimated to increase target yields by 20%.

Target yields for dry years have also been calculated on the basis of simulation results. The ratio of average simulated yield in dry years and in normal years has been calculated for each combination of rainfall zone and soil type. The target yield in a dry year is then obtained by multiplying the target yield in a normal year by that rainfall zone- and soil type-specific ratio.

In addition, harvest and post-harvest losses have been taken into account, by using in the model net yields (= 80% of target yields).

As crop residue production depends on production technique, soil type and rainfall, no fixed value could be used. Therefore, crop residue production was calculated as a function of target yield for each activity in each rainfall zone.

Although straw can be used for building purposes, fuel or fodder, only the latter has been taken into account in this study. The quantity available for animal consumption was expressed as a fraction of total production, determined by its physical properties and chemical composition (not all parts are consumable), harvest and post-harvest losses, and accessibility.

The quality was expressed in terms of N-content in dry matter (cf. Breman & de Ridder, 1991). Four quality classes have been distinguished: *(i)* low (N < 7.5 g kg^{-1}); *(ii)* moderate (N between 7.5-10.0); *(iii)* good (N between 10.0 and 17.5) and *(iv)* excellent (N > 17.5; average 20).

Inputs in crop production techniques comprise:

1. **Soil**, i.e. soil type;
2. **Inorganic fertilizer, farmyard manure or area of fallow**; Nitrogen, phosphorus and potassium (N, P and K) may originate from natural sources during fallowing, from manure or inorganic fertilizer, or a combination of the three. The requirements (in elementary form) have been calculated according to NUREQ (Chapter 3).
3. **Labour**; Labour requirements have been defined as the number of man-days required to complete an operation including the necessary travelling time. One man-day [mnd] represents the work accomplished by a male adult during one working day.

   Labour requirements have been specified for the following operations (in chronological order): cleaning of the field, transport of manure, application of manure, application of the basal dose of inorganic fertilizer, land preparation, soil levelling, sowing, transplanting, weeding (up to 3 times), inorganic fertilizer top dressing (up to 3 times), biocide spraying, dike maintenance, irrigation, bird scaring, guarding, harvesting, threshing and winnowing, transport of produce.

   For some operations labour requirements are a function of the level of input or output, for instance, for transport and application of farmyard manure (input), which in turn is function of the target yield (output).
4. **Monetary inputs**; These are subdivided in capital charges and operating costs, the former referring to the annual depreciation of capital goods, such as plough, harrow, sowing machine, etc. Interest payments have not been included. Operating costs include the costs of seeds, fuel for irrigation, dike maintenance, the hired threshing-machine, and biocides.
5. **Oxen**; It has been assumed that animal traction is provided by oxen only, and in analogy with human labour requirements, one oxen-team-day represents the work accomplished by a pair of oxen during one working day. The required number of oxen per hectare is calculated for each relevant period (land preparation, first weeding) on the basis of the time required to complete an operation and the length of the available period. The maximum value is used as input in the model. Furthermore, accessibility of ploughs and oxen could be a problem. This has been included in the model by excluding exchange of ploughs and oxen between agro-ecological zones. To account for imperfect exchange within a zone, the required number of ploughs and oxen has been set 25% higher than in case of perfect exchange.

In total 59 crop activities (combinations of crop, production technique and soil type) were defined, their inputs and outputs being summarized in Table 4.3.

Table 4.3. *Annual inputs and outputs of the various crop activities: soil type, fallow [fallow years per year of cultivation], chemical fertilizer: N, P, K [kg per ton target yield], farmyard manure [kg DM kg^{-1} DM target yield], total labour [man-day ha^{-1}], capital charges [Capc, 1000 FCFA ha^{-1}], operating costs [Operc, 1000 FCFA ha^{-1}], oxen [number ha^{-1}], marketable yield and crop residues [1000 kg DM ha^{-1}] (van Duivenbooden et al., 1991).*

CROP/ TECHNOLOGY[a]	INPUTS										OUTPUTS	
	Soil type	Fallow	N	P	K	Manure	Labour	Capc	Operc	Oxen	Target yield	Residue
Millet/1	B1,B2,C1,C2,D1	4-5	-	-	-	-	62	0.7	0.2	-	0.2-0.5	1.0-2.8
Millet/2	B1,B2,C1,C2,D1	-	-	-	-	3-8	75	0.7	0.2	-	0.2-0.5	1.0-2.8
Millet/3	B1,B2,C1,D1, E1a,E2a,F1	6-8	-	-	-	-	56	2.4	0.2	0.33	0.2-0.6	0.9-3.2
Millet/4	B1,B2,C1,D1, E1a,E2a,F1	-	-	-	-	4-9	73	2.4	0.2	0.33	0.2-0.6	0.9-3.2
Millet/5	B1,B2,C1,F1	-	15-26	-	6-19	3-5	77	2.7	0.3	0.33	0.3-1.0	1.4-4.6
Millet/6	B1,B2,C1,F1	-	44-74	4-6	21-52	1-2	117	9.6	6.6	0.75	0.8-2.4	2.7-6.2
Fonio	C1	7	-	-	-	-	46	0.7	3.3	-	0.3-0.4	0.6-0.9
Sorghum/1	G	6	-	-	-	-	39	0.7	0.3	-	0.6	4.7
Sorghum/2	G	-	105	15	59	-	52	1.0	0.4	-	1.0	5.5
Groundnut1	C1	2	-	4	-	-	83	4.7	19.5	0.50	0.8	0.9
Groundnut2	C1	-	22	6	12	-	100	6.2	22.5	0.50	1.4	1.2
Cowpea/1	B2,C1,C2,D1,F1	3	-	2-7	-	-	82	3.9	12.1	0.33	0.1-0.8	0.4-1.8
Cowpea/2	B2,C1,F1	-	33-58	12-14	44-83	1-2	130	8.0	15.1	0.75	0.3-1.5	1.0-2.6
Shallot	NR1	-	-	-	-	0.2	1963	2.9	202.5	-	35.0*	-
Vegetables	NR1	-	-	-	-	0.3	1389	2.9	53.5	-	16.0*	0.7
Fodder	B2,C1,F1	-	13-16	3-5	14-21	0.3	60	8.0	15.1	0.75	1.4-4.6	-
Bourgou	E1b,E2b,F3b	-	26	4	20	0.2	113	37.6	64.1	0.13	15.0	-
OP-rice	E1b,E2b,F3b	5-7	-	-	-	-	55	4.0	7.6	0.50	0.6	2.4
P-rice/1	F3b	-	77	3	31	0.9	104	34.4	14.9	0.50	1.3	5.2
P-rice/2	F3b	-	99	6	52	1.5	117	34.4	27.9	0.50	2.8	8.4
IR-rice	F3b	-	67	5	18	0.6	452	350.0	180.0	0.50	9.0	11.0

NR1: soil type not relevant as soil properties are affected by manure application.
[a]) indicates intensification level; *) fresh weight.

4.3.2 Livestock

Cattle, sheep, goats, camels, donkeys, horses, pigs, poultry and wild game are present in the region, however strongly varying in importance. As for cropping systems, only the major production techniques have been included with the degree of differentiation depending on the relative importance of the animal species. Twenty-two activities have been distinguished, based on four criteria: *(i)* animal species (cattle, sheep, goats, donkeys, and camels), *(ii)* main production objective (meat and/or milk or traction/transport), *(iii)* target production level (low, intermediate or high) and *(iv)* mobility of animals, for which the following definitions have been applied:

- Sedentary: the animals stay year-round within a 6 km radius of a permanent water point;
- Semi-mobile: during the hot season (February-June) the animals graze the pastures between 6 and 15 km from a permanent water point. Overnight they stay in temporary camps; they return at least once every three days to the permanent water point to be watered;
- Migrant: during the rainy season (July-October) the animals graze wet season pastures beyond a 15 km radius from a permanent water point. During the dry season they stay within that distance.

Regardless of their mobility, all animals have access to crop residues left in the field after harvest during the cold season (November-January).

All livestock activities are expressed per Tropical Livestock Unit [TLU], an hypothetical animal of 250 kg liveweight (cf. Le Houérou & Hoste, 1977).

Target annual meat production levels range from 22 to 71 kg liveweight TLU^{-1} for cattle and from 40 to 100 for small ruminants. Annual milk production for human consumption varies from 0 to 520 kg TLU^{-1} for cattle, from 100 to 200 kg TLU^{-1} for goats and from 0 to 50 kg TLU^{-1} for sheep. For donkey and camel activities, the number that can be used for traction/transport is the main product. By-products (e.g. hides) have not been included in the model, except for manure. Manure availability has been calculated on the basis of the assumptions given in Table 4.4. Manure of camels can only be used as fuel.

Table 4.4. Manure availability [fraction of annual production] for arable crops, collected from corals (80% collection) and during grazing in arable fields.

Species (mobility)	Period	Corral hours	Field hours	Manure	
Cattle (sedentary), sheep & goats (sedentary & semi-mobile) & donkeys	July-October	12	0	0.13	
	November-January	0	15	0.16	
	February-June	12	0	0.17+	
					0.46
Cattle (semi-mobile)	July-October	6	0	0.07	
	November-January	0	15	0.16	
	February-June	6	0	0.08+	
					0.31
Cattle (migrant)	July-October	0	0	0	
	November-January	0	15	0.16	
	February-June	6	0	0.08+	
					0.24
Sheep & goats (migrant)	July-October	0	0	0	
	November-January	0	15	0.16	
	February-June	12	0	0.17+	
					0.33

Inputs of livestock activities comprise:

1. **Forage**; Biomass in terms of both quantity and quality. Its availability is specified separately for the wet season and the dry season. Analogously to crop by-products, four quality classes have been distinguished on the basis of N-content. Browse has been treated as a separate category, available as a possible forage source in the dry season for goats and camels only. The estimated average N-content of browse in the region is 14 g kg^{-1} DM. Crop by-products and concentrates are alternative feed sources. On the basis of the available feed sources, four possible diets (I-IV, Table 4.5) have been distinguished, characterized by average N-contents of 9, 10, 11 and 12 g kg^{-1} DM and digestibilities of 52, 54, 56 and 59%, respectively.
2. **Labour**; Labour requirements have been specified for herding including watering, milking and veterinary care.
3. **Monetary inputs**; These consist almost exclusively of salt-bricks, vaccines and possibly concentrates. To attain the production levels specified for the semi-intensive cattle activity, additional investments in herd management (equipment, stables and other structures) are needed.

In total 23 livestock activities (combination of animal species, mobility and main product) were defined. The inputs and outputs of these activities are summarized in Table 4.5.

Table 4.5. *Annual inputs and outputs in livestock activities per TLU: intake of quality diet comprising forage, browse and concentrates [1000 kg DM], total labour in the wet and dry season [man-day], money [1000 FCFA TLU^{-1}], meat [kg liveweight], milk [kg], animals [number] and recoverable manure [kg DM] (van Duivenbooden et al., 1991).*

ACTIVITY CODE	MAIN PRODUCT	MOBILITY	INPUTS: INTAKE DIET	FORAGE	BROWSE	CONC.	LABOUR WET	LABOUR DRY	MONEY	OUTPUTS: MEAT	MILK	ANIMALS	MANURE
Cattle													
B1.	Oxen	sedentary	II	2.0	-	-	2	15	12.9	0	0	0.77	580
B2.	Meat	semi-mobile	I	2.0	-	-	3	8	5.4	37	0	-	300
B3.	Meat	semi-mobile	II	2.0	-	-	3	10	5.4	57	93	-	290
B4.	Meat	migrant	I	2.0	-	-	3	8	5.4	37	0	-	230
B5.	Meat	migrant	III	2.1	-	-	3	10	5.4	71	219	-	220
B7.	Milk	sedentary	II	2.1	-	-	4	12	5.4	54	165	-	460
B8.	Milk	sedentary	III	2.2	-	-	4	12	5.4	62	377	-	450
B9.	Milk	migrant	II	2.1	-	-	4	12	5.4	54	165	-	240
B10.	Milk	migrant	III	2.2	-	-	4	12	5.4	62	377	-	230
B11.	Milk	sedentary	IV	1.9	-	0.3	4	13	9.2	61	518	-	720
B12.	Milk	sedentary	IV	2.2	-	-	4	13	9.2	61	518	-	720
Sheep													
B13.	Meat	sed. & s-m.	I	2.3	-	-	13	40	6.6	97	0	-	520
B14.	Meat	sed. & s-m.	III	2.4	-	-	14	43	6.6	121	62	-	480
B15.	Meat	migrant	I	2.3	-	-	13	40	6.6	97	0	-	370
B16.	Meat	migrant	III	2.4	-	-	14	43	6.6	121	62	-	340
B17.	Meat	sedentary	IV	-	-	1.5	5	16	4.2	89	19	-	500
Goats													
B18.	Meat	sed. & s-m.	I	2.0	0.4	-	13	39	6.6	68	0	-	520
B19.	Meat	sed. & s-m.	III	1.7	0.8	-	14	42	6.6	96	180	-	510
B20.	Meat	migrant	I	2.0	0.4	-	13	39	6.6	68	0	-	370
B21.	Meat	migrant	III	1.7	0.8	-	14	42	6.6	96	180	-	370
Donkeys													
B22.	Transport	sedentary	II	2.9	-	-	8	6	5.3	-	-	2.00	610
Camels													
B23.	Transport	migrant	II	2.4	0.4	-	2	14	36.3	75	240	0.83	320

4.4 Scenario definition

In this study, the goal 'marketable crop production' is maximized. Marketable crop production is defined as total crop production minus food needs of the rural population in a normal year and is expressed in tons dry matter. In this way, food needs are explicitly taken into account, so that the monetary counter value of the optimized goal variable can be used to buy other commodities.

Results of this goal are expressed as marketable **grain** production, because grains are the staple food. Cowpea and groundnut are also included in this parameter. Shallots and other vegetable products are not further considered because they are selected maximally under all conditions.

Prices attached to products and inputs are listed in Table 4.6. Food needs of the rural population comprise at least grains, vegetables, meat and milk (Subsection 4.2.4).

The three scenarios can be described as:

- I; This explores the possibilities with restricted inorganic fertilizer availability, comparable to current use in the region. Data on actual inorganic fertilizer use are scarce, but on the basis of information from Opération Mil Mopti (Omm, 1988), it is estimated that 5% of the rainfed crops receive 40 kg N ha^{-1}, 10% receive 10 kg and the remainder nothing, resulting in an average use of 3 kg N ha^{-1}. Polder rice receives 20 kg N ha^{-1} and irrigated rice 93 kg N ha^{-1} (Opération Riz Mopti, unpublished). This implies an average N-fertilizer rate of about 7 kg ha^{-1} of cultivated land. For P and K, however, such estimates could not be made.
  For practical reasons, these amounts of N-fertilizer have been converted in monetary units. Considering the other monetary inputs, a maximum is set to the goal 'total monetary inputs in cropping systems', at 5 10^9 FCFA.
- II; This explores the possibilities with a somewhat higher inorganic fertilizer availability. The maximum expenditure is set at 11 10^9 FCFA.
- III; In this scenario to limit is set to expenditures in cropping activities, allowing potential inorganic fertilizer use according to the region's potential.

Table 4.6. *Prices [FCFA] of outputs and inputs as defined in the IMGLP-model; crop products and concentrates per kg DM (except for shallots and other vegetables, i.e. fresh weight), meat per kg live-weight, milk per kg, and fertilizer per kg nutrient in elementary form*

CROPS		LIVESTOCK	
millet	55	beef	320
sorghum	56	mutton	340
rice (paddy)	70	goat meat	340
fonio (hulled grain)	70	milk (at Mopti)	180
groundnut (unshelled)	75	milk (elsewhere)	0
cowpea (shelled)	75		
shallots (bulb & leaf blades)	59		
other vegetables	96		
crop residues	0		
manure	0	concentrates	44
N	450		
P	1250		
K	450		

To guarantee a certain income for the rural population, a restriction (minimum value) is imposed on regional gross revenue in each scenario. It is based on a previously calculated maximum value, i.e. 67 billion FCFA (using the same IMGLP-model; Veeneklaas *et al.*, 1991). Food needs, however, could not be covered by local production under those conditions. Hence, to increase the scope for meeting these food needs, the minimum value of regional gross revenue is set at 50 billion FCFA. For the restrictions on other goals, the values of Veeneklaas *et al.* (1991) have been applied.

4.5 Results

4.5.1 Highlights

Values of marketable grain production and of other goals in the three scenarios are given in Table 4.7, which also lists values of other restrictions imposed.

Food needs can be met in normal years with surpluses increasing with increasing fertilizer availability (Table 4.7, line 3). It can, however, not be met in dry years in either scenario (line 14), grain deficits ranging from 53 via 36 to 2% of food needs in scenario I, II, and III, respectively. A further increase in marketable grain production is prevented by the following binding restrictions:

- Minimal regional gross revenue in all three scenarios (line 8);
- Maximum total monetary inputs in cropping systems, by definition in scenarios I and II (lines 9a and 9b);
- Minimum rice production in dry years in scenarios I and II (line 12);
- Maximum number of animals at risk (i.e. that need to be supplemented or transferred to other regions in dry years because of feed shortages) in all three scenarios (line 15);
- Maximum emigration in all three scenarios (line 17).

Livestock numbers and their production increase with increased inorganic fertilizer availability (lines 4-7). Fishery outputs attain maximum values in all three scenarios, but are not further discussed here.

Results on land use, crop production, fertilizer requirements and animal husbandry are discussed in more detail.

Table 4.7. Values of the goal variables under different upper limits on monetary inputs of crop activities in the three scenarios. I: restricted, II: intermediate and III: unrestricted inorganic fertilizer application.

GOAL VARIABLE	RESTRICTION	SCENARIO I	II	III
Production, normal year[a] [1000 ton]				
1. Millet, sorghum & fonio	> 160	180	251	386
2. Rice	> 20	41	41	30
3. Marketable grain production	> 0	18	90	221
4. Total meat	> 23	99	104	136
5. Beef	> 12	68	73	61
6. Milk	> 170	201	216	208
7. Animals [1000 TLU]	> 0	1707	1723	1917
Monetary targets, normal year[a] [10^9 FCFA]				
8. Gross Revenue of crops, livestock and fisheries	> 50	50*	50*	50*
9a. Monetary inputs crops	< 5	5*		
9b. Monetary inputs crops	< 11		11*	
9c. Monetary inputs crops	< 40			29
10. Monetary inputs livestock	< 20	12	12	13
Production, deficits and risks in a dry year[a] [1000 ton]				
11. Millet, sorghum & fonio	> 80	87	125	195
12. Rice	> 10	10*	10*	11
13. Crop products	> 0	196	234	307
14. Regional grain deficit	< 150	115	77	4
15. Number of animals at risk [1000 TLU]	< 400	400*	400*	400*
Miscellaneous				
16. Employment [1000 mn-yr]	> 300	313	319	359
17. Emigration [1000 persons]	< 250	250*	250*	250*

*) binding, i.e. the goal restriction imposed is an acting constraint on attaining a better value of the goal optimized.
a) normal and dry years are explained in the text.

4.5.2 Land use and crop production

The predominant land use, in terms of area, is rangeland, with the larger part between 6 and 15 km from a permanent water point (Figure 4.3). Fallow land also is important, especially in scenario I. The area decreases with increasing fertilizer availability (Table 4.9, page 72), and consequently the remainder can be used as pasture. Land in the region is more intensively exploited in scenario III, as the wasteland area (including land non-suitable for agriculture) is smaller.

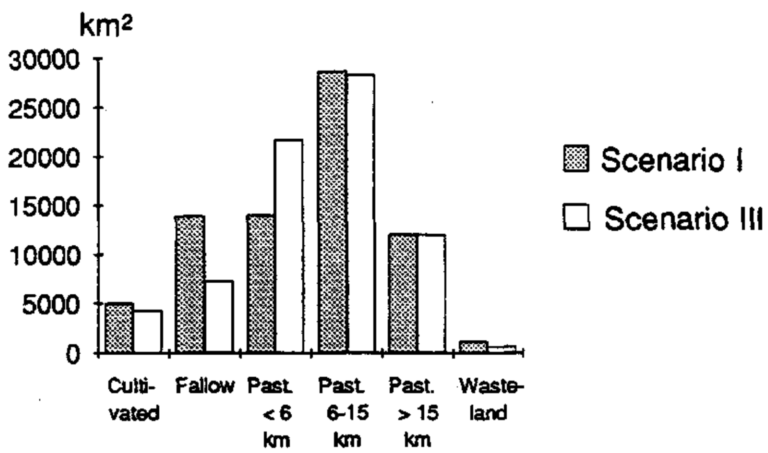


Figure 4.3. *Regional land use [km²] in scenarios I and III, with restricted and unrestricted inorganic fertilizer availability, respectively.*

Table 4.8. *Breakdown [% of cultivated land] of crops according to the three production levels in the three scenarios.*

CROP	LAND USE		
	scenario I	scenario II	scenario III
Extensive			
Millet	50.8	39.4	21.5
Sorghum	0.4	0.4	0.0
Fonio	0.3	0.8	10.7
Rice	11.0	11.1	0.2
Subtotal	62.5	51.7	32.4
Semi-intensive			
Millet	32.7	31.5	0.0
Sorghum	0.0	0.0	3.4
Cowpea	1.3	1.2	2.3
Groundnut	1.7	1.9	2.1
Rice	1.0	1.0	2.8
Subtotal	36.7	35.6	10.6
Intensive			
Millet	0.0	11.9	52.0
Cowpea	0.0	0.0	1.2
Fodder crops	0.0	0.0	2.9
Onion & other vegetables	0.7	0.7	0.8
Rice	0.1	0.1	0.1
Subtotal	0.8	12.7	57.0
Total	100.0	100.0	100.0
Total absolute [km²]	5 046	4 976	4 381

Cultivated land is the smallest but one part in all scenarios, although this implies an expansion compared to the current situation (about 4000 km^2). The limited expansion in cultivated area in scenario III is accompanied by intensification of various crops, especially of millet, and a higher degree of diversification (Table 4.8). This table also shows that in scenario III extensive rice cultivation is almost abolished. It is partly replaced by semi-intensive rice and flood-retreat sorghum production. Further, the fonio area is expanded and fodder crops are additionally cultivated. These shifts are probably the result of:

- The combination of the binding restriction of regional gross revenue and the relative economic profitability of sorghum and fonio. Fodder crops are grown to fatten sheep, that are sold at the market at a favourable price.
- The binding restriction of labour availability, especially in the period of first weeding (sorghum requires no labour in that period) and that of millet harvest (fonio is harvested earlier). Differences per period and per agro-ecological zone are considerable, but not further presented.

Increased fertilizer availability also affects the cropping areas in each of the agro-ecological zones (Figure 4.4). This figure also shows the shift between cropping areas in the different scenarios.

With increased intensification, average grain production per ha cultivated land in normal years increases from 467 (I) via 620 (II) to 1036 kg DM in scenario III. Average yields of millet (the major crop) amount to 420, 600 and 1120 kg ha^{-1}, respectively. Consequently, marketable grain production can increase in a normal year from 36 to 524 kg ha^{-1}.

For planning of produce transport within the region, production of each crop per agro-ecological zone is calculated (Figure 4.5) and surplus and shortage areas are identified. For instance, rice production is insufficient in all but one agro-ecological zone to meet its requirements. Total subregional crop production is insufficient to meet food needs in normal years in the three northern (driest) agro-ecological zones in all three scenarios and in a fourth zone in scenarios I and II.

Food needs can only be met in dry years if, in addition to unrestricted fertilizer availability and emigration (scenario III), sacrifices are accepted. This would imply adapting, for instance, the binding restriction of regional gross revenue.

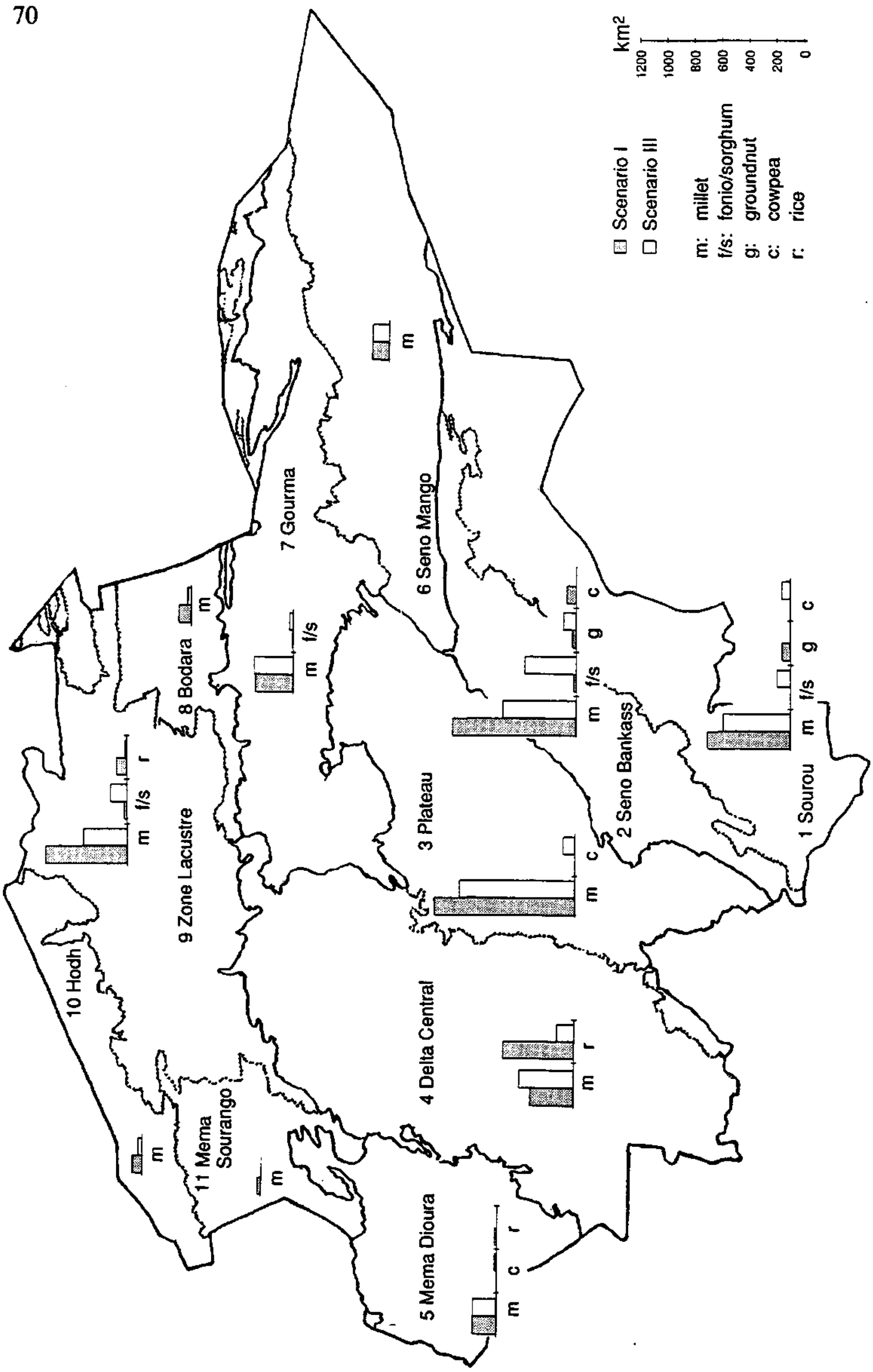


Figure 4.4. Distribution of cultivated area [km²] among the various agro-ecological zones in scenarios I and III, with restricted and unrestricted inorganic fertilizer availability, respectively..

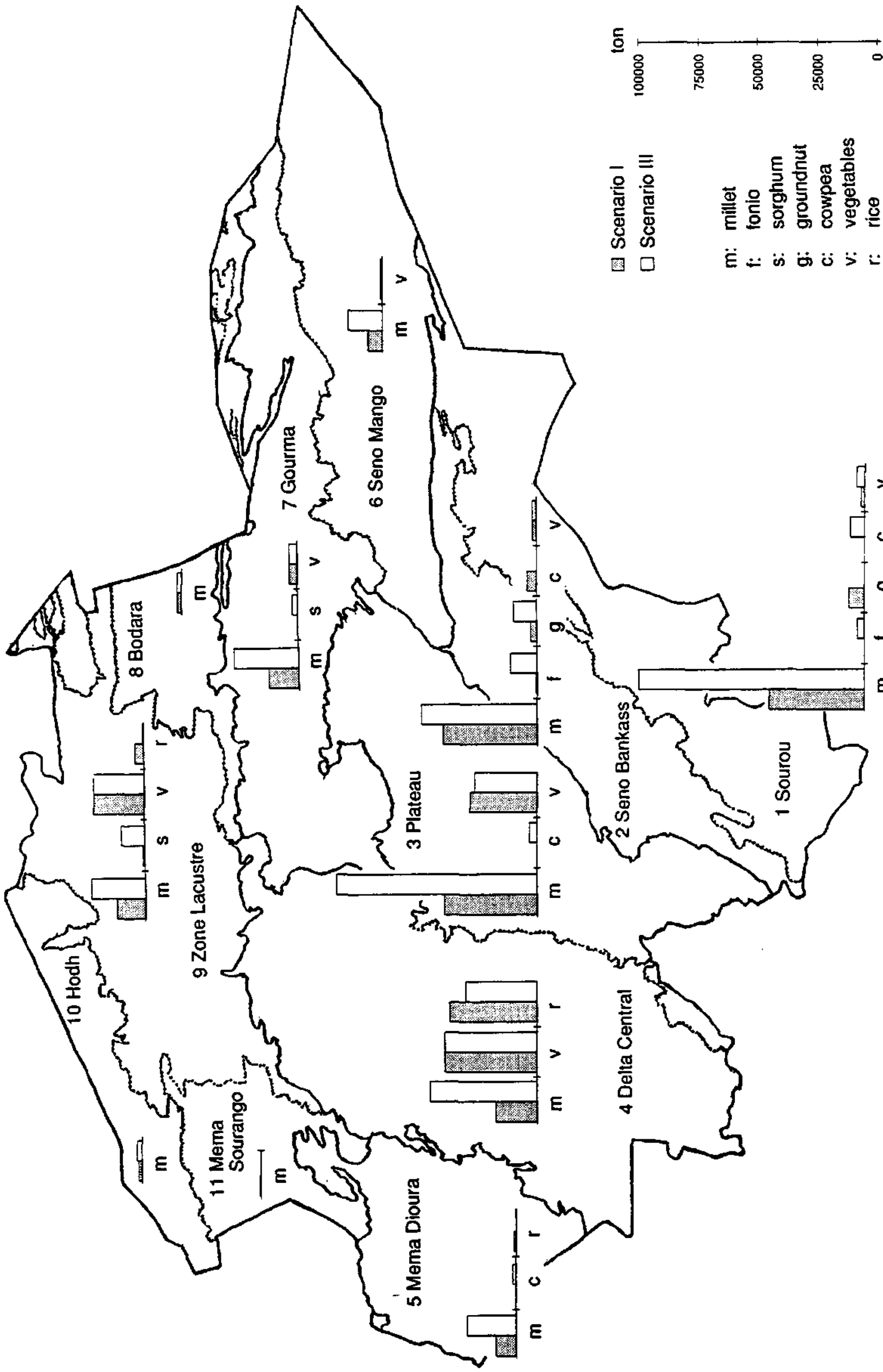


Figure 4.5. *Crop production [ton] in the various agro-ecological zones in scenarios I and III. Vegetables are expressed in fresh weight, others in dry weight.*

4.5.3 Inorganic fertilizer and farmyard manure requirements

With increasing inorganic fertilizer availability, the increase in use is highest in absolute sense for nitrogen fertilizer, in relative sense for phosphorus and potassium fertilizers, albeit varying per crop (Table 4.9) and per agro-ecological zone (Table 4.10). The latter table can be used for transport planning, in terms of both quantity and quality.

The dramatic increase in average N-application for rice (Table 4.9) is the result of disappearance of extensive rice production. N-application of semi-intensive and intensive production techniques combined differ only slightly among scenarios I and III, at 241 and 226 kg ha^{-1}, respectively.

Table 4.9. *Application of inorganic nitrogen, phosphorus and potassium fertilizers and manure in the various crop activities in the three scenarios.*

CROP	APPLICATION		
	scenario I	scenario II	scenario III
Nitrogen[a] [kg ha^{-1}]			
Millet, sorghum & fonio	4	18	54
Groundnut	30	30	30
Cowpea	0	0	19
Fodder crops	0	0	45
Rice	22	22	209
average	7	18	57
Phosphorus[a] [kg ha^{-1}]			
Millet, sorghum & fonio	0	2	7
Groundnut	9	9	9
Cowpea	4	3	9
Fodder crops	0	0	17
Rice	1	1	9
average	0.3	2	8
Potassium[a*] [kg ha^{-1}]	1.3	9	35
Manure [kg DM ha^{-1}]			
Millet, sorghum & fonio	1040	1020	1130
Cowpea	0	0	510
Fodder crops	0	0	930
Vegetables	8790	8790	8790
Rice	390	390	4000
average	980	960	1220
Fallow [ha ha^{-1}]	2.8	2.7	1.7

[a]) in elementary form.
*) no specification per crop available.

__Table 4.10.__ Relative requirements of nitrogen, phosphorus and potassium, (N:P:K, in elementary form) and total requirement [1000 ton] in the various agro-ecological zones and in the Region in the three scenarios.

Agro-ecological zone	scenario I		scenario II		scenario III	
	N:P:K	Total	N:P:K	Total	N:P:K	Total
Sourou	14:1:2	0.9	7:1:4	6	6:1:4	10
Seno Bankass	5:1:1	0.3	5:1:4	1	6:1:4	4
Plateau	1:0:0	0.3	7:1:4	4	6:1:4	8
Delta Central	26:1:8	2	27:1:9	2	12:1:6	8
Mema Dioura	1:0:0	0.2	1:0:0	0.2	7:1:5	2
Seno Mango	1:0:0	0.1	1:0:0	0.1	7:1:4	2
Gourma	1:0:0	0.2	1:0:0	0.2	7:1:4	3
Bodara	1:0:0	-	1:0:0	-	6:1:4	0.2
Zone Lacustre	1:0:0	-	5:0:1	-	10:1:6	5
Hodh		0	1:0:0	-	7:1:4	0.2
Mema Sourango		0	1:0:0	-		0
REGION	21:1:4	4	9:1:4	14	7:1:4	43

- denotes less than 0.1 ton.

The higher phosphorus requirements in scenario III are mainly the result of higher P-requirements in intensive millet activities. P-requirements also increase for cowpea, fodder crops and rice, but they occupy only a limited area.

Despite the increase in inorganic fertilizer availability, average farmyard manure requirements also increase (Table 4.9). This is the result of the prerequisite that crop nutrient requirements can not be met by inorganic fertilizers only. Furthermore, differences in cropping patterns contribute to this increase. Farmyard manure is mainly used for millet, of which the requirements decrease from 89 (scenario I) to 81% of the total manure requirements (scenario III).

Regional farmyard manure requirements increase from 494 000 (scenario I) to 535 000 ton (scenario III), to be met by manure availability from various animal husbandry activities. This has been possible in all three scenarios, while surplus manure availability (not further used nor exchanged with inorganic fertilizer in the model) occurs in four (scenario I) or five (scenarios II and III) agro-ecological zones.

4.5.4 Animal husbandry

Increased fertilizer availability also affects animal husbandry activities. Both, number and distribution among animal species change, with a higher degree of diversification in scenario III (Table 4.11).

Table 4.11. *Number of animals [1000 TLU] in the various animal husbandry activities in the three scenarios.*

Animal type/main product activity no, mobility, production level		ANIMALS scenario I	scenario II	scenario III
Cattle/oxen				
B1 sedendary	low	273	214	265
Cattle/meat				
B2 semi-mobile	low	136	121	55
B3 semi-mobile	intermediate	2	31	43
B4 migrant	low	0	0	0
B5 migrant	intermediate	845	899	774
B6 vacant	-	-	-	-
Cattle/milk				
B7 sedentary	low	56	64	19
B8 sedentary	intermediate	0	0	0
B9 migrant	low	0	0	0
B10 migrant	intermediate	0	0	0
B11 sedentary	semi-intensive	0	0	4
B12 sedentary	semi-intensive	0	0	0
Total cattle		*1312*	*1265*	*1137*
Sheep/meat				
B13 sed & s-m*	low	124	129	136
B14 sed & s-m*	intermediate	0	31	260
B15 migrant	low	13	14	25
B16 migrant	intermediate	30	0	80
B17 sedentary	semi-intensive	16	18	160
Goats/meat & milk				
B18 sed & s-m*	low	156	156	21
B19 sed & s-m*	intermediate	8	0	10
B20 migrant	low	0	0	19
B21 migrant	intermediate	0	0	0
Total small ruminants		*347*	*348*	*711*
Donkeys/transport				
B22 sedentary	intermediate	32	32	32
Camels/transport				
B23 migrant	low	16	16	16
Total all animals		*1707*	*1661*	*1896*

*) sed & s-m = sedentary & semi-mobile

Total number of cattle and goats decreases with increase in fertilizer availability, but that is more than compensated by an increase in the number of sheep, especially in those activities utilizing the rangeland areas close to the villages (i.e. sedentary and semi-mobile activities, B14; sheep fattening, B17). Although the intensification level of crops is low in scenario I, the number of oxen is higher than in the other scenarios (Table 4.11, B1). It is probably selected here for the relative high fraction of manure collected, and in scenario III for its traction. Apparently, requirements for either of these functions are lower in scenario II. Semi-intensive milk production becomes profitable in scenario III around Mopti-town, despite the required concentrates (Table 4.11, B11).

Calculated herd size (1.7-1.9 million Tropical Livestock Units, Table 4.11) in the three scenarios exceeds that established in the region in June 1987 (1 123 000 TLU; RIM, 1987), but is more or less in agreement with the number of 1 700 000 observed in the period 1977-1987 (IUCN, 1989). However, the number of animals at risk in dry years (Table 4.7, line 15) is considerable (21 - 24%) in all three scenarios.

Regional meat production ranges from 99 000 to about 140 000 ton, considerably exceeding meat needs in all three scenarios. Consequently, this relatively highly priced surplus (Table 4.6) contributes substantially to regional gross revenue (e.g. 80% in scenario III).

Regional farmyard manure availability (about 35% of the manure produced; Subsection 4.3.2) exceeds requirements, although the fraction of manure that is utilized for cropping techniques is high, i.e. 0.81, 0.80 and 0.74, in scenario I, II and III, respectively. For several agro-ecological zones this fraction equals one, so that all manure is used.

4.6 Scenario variants and post-model analysis

Variants of the scenarios analysed here can be used to obtain further information in support of result interpretation, while in the post-model analysis, aspects that have not been incorporated in the IMGLP-model are taken into account. Examples of such aspects are population growth, ownership of production factors, land tenure, marketing facilities and social aspects, of which some are treated below. In addition, ability and willingness (acceptance) determine the possibilities for realization of a development scenario.

4.6.1 Emigration rate

So far, in the scenarios a substantial emigration rate has been allowed. It can, however, be the goal of the government to keep as many people as possible in the region. That has consequences for food needs. Therefore, this situation has been examined for scenarios I and III (referred to as scenarios I^+ and III^+, respectively).

Food needs could not be met in scenario I^+ in normal years, hence its results are not further discussed. Results of scenario III^+ show for normal years a reduction in marketable crop production of about 50 000 t (13%), a decrease of 21% in marketable grain production and a 50% reduction in gross regional revenue (25 versus 50 10^9 FCFA), while other goal variables attained more or less identical values. Furthermore, the results show that from a social point of view, emigration or employment opportunities outside the agricultural sector are necessary, because labour requirements are only 1% higher than in scenario III.

4.6.2 Population growth

Realization of the scenarios also depends on future perspectives. Considering the annual population growth rate of 2.8% (average for Sahel countries; Club du Sahel, 1991), the possibilities for agricultural development in scenario I seem very limited, because within 3 years the food needs of the population can not be met in normal years. Of course, food needs may be reduced by forcing people out of the region, but that does not seem feasible because no obvious alternatives are available. Therefore, exploring the possibilities for agricultural development seems more promising in scenarios II and III. In the former, it takes about 12 years before the critical population size is reached.

4.6.3 Fertilizer availability

In scenario II, regional inorganic fertilizer requirements (elementary form) increase to about 14 000 ton (Table 4.10). This would imply a considerable increase in total inorganic fertilizer import in Mali, currently about 12 000 ton (1987/88; FAO, 1991b). The inadequate supply of inorganic fertilizer is, however, a continuous problem in West Africa for various reasons, such as marketing constraints, low priority in transport, excessive bureaucracy, inadequate infrastructure (Sijm, 1992; Makken, 1991; Daapah, 1989; Schultz *et al.*, 1987) and the supply through cooperatives and extension services to the farm level (Thompson & Baanante, 1988). In addition, there is often a lack of crop-specific fertilizer recommendations and application of fertilizer intended for cash crops to food crops (Vlek, 1990). This limited supply also contributes to high prices (Makken, 1991; Vlek, 1990; Daramola, 1989).

In scenario III, these constraints become even more important, and the question arises if the country can afford investments to alleviate these constraints, compared to costs of food imports in dry years (difference between scenarios II and III).

4.6.4 Uneven distribution of costs and profits

Monetary issues have been dealt with only at the regional level, i.e. the minimum (restricted) regional gross revenue that can be attained. However, it should be realized that in the region two groups are present, pastoralists and farmers, with complete different monetary inputs and revenues.

Farmers have to spent high monetary inputs in crops per unit product (shallots and other vegetables excluded), i.e. 19, 34 and 62 FCFA kg^{-1} in scenario I, II and III, respectively, with the major part spent on inorganic fertilizer, i.e. 9, 23 and 50 FCFA kg^{-1}, respectively. Farmers are reluctant to invest in inorganic fertilizers, because of the low current farmgate product price of 55 to 75 FCFA kg^{-1} (Table 4.6) and the fact that only a small part of the products can be sold. The latter is partly caused by a relatively small urban market, as a result of large imports of wheat and rice (IOV, 1991). On the other hand, monetary inputs in livestock are lower (costs for supplements or transport of animals in dry years are not included), while revenues are much higher. This suggests a policy that is geared to more integration of the grain component and livestock component of agricultural production. This also existed in former days, but is now unacceptable form of feudal dependence.

Apart from this lack of integration, livestock marketing may present a problem, considering the calculated regional meat export in scenario II (i.e. 93 000 ton liveweight, or about 373 000 TLU) in comparison to the current national cattle export of 140 000 TLU (Club du Sahel, 1990). The market is further affected by competing imports of low-priced meat from e.g. the EG (priced at 44% of local meat; Club du Sahel, 1990). The possible consequences for regional gross revenue in the defined scenarios, are evident.

4.6.5 Possible steps for further analysis

To examine the possibilities for the policy to meet food needs and guarantee an acceptable income for both farmers and pastoralists on a sustainable basis, the effects of measures can be investigated. They may comprise:

- Adaptation of prices.

  Veeneklaas *et al.* (1991) demonstrated that a 50% reduction in inorganic fertilizer price increases fertilizer use, marketable crop production (+ 84 000 ton) and regional gross revenue (+ 2.7 10^9 FCFA) and resulted in a lower regional grain deficit in dry years (- 46 000 ton).

  A 50% increase in output prices, however, resulted in smaller changes in marketable crop production (+ 13 000 ton), regional gross revenue (+ 1.8 10^9 FCFA), and regional grain deficit in dry years (- 6 000 ton). Sijm (1992) also considers supporting producer prices ineffective. Consequently, subsidizing inorganic fertilizers seems a better measure, although such subsidies have not been granted since 1988 in Mali (IOV, 1991). A lower fertilizer price can also be achieved by improvement of transport infrastructure (e.g. transport facilities between main harbours (Dakar, Senegal; Abidjan, Ivory Coast) and Mali) and ensuring that road controls installed by various organisations can be passed without payment of levies.

  Further, a levy on imported meat could help to improve marketing of local meat, but for the local population this would imply no access to low-priced meat.

- Restriction of animal number.

  Although theoretically the calculated number of animals can be supported, problems may occur, for instance, with passing-through permits (land tenure problem). In addition, in the real-life situation the risk remains that farmers can not afford to pay for supplements in dry years, with associated consequences for overgrazing of rangeland, mortality and imbalances in the herd structure leading to lower production.

  A lower number of animals has also consequences for cropping techniques as a result of lower manure availability.

- Development of the non-agricultural sector.

  To increase employment, allow payment of imports from outside the region and reduce the dependence of the region on animal husbandry for gross revenue, development of the non-agricultural sector is imperative.

The effects of some of these measures can be analyzed with the IMGLP-model, e.g. through adapting restrictions and prices. The consequences for agricultural development can be evaluated, followed by a new post-model analysis. In addition, the model can be run with optimization of different goals (e.g. gross revenue) with a restriction on marketable crop production. Such analyses should be carried out in close cooperation with stakeholders in the region and national authorities.

4.7 Concluding remarks

The IMGLP-model covers all major agricultural activities (including potential ones) of the region. It contains all known relations among these activities and between activities and natural and human resources, in quantitative terms (input-output format). Therefore, a great number of data are required.

The model can be used to examine consequences of optimizing certain goals for land use, intensification level and degree of exploitation of natural and human resources. Examples are maximizing regional gross revenue (Veeneklaas *et al.*, 1991) and marketable crop production (this chapter). It moreover, can clarify the trade off between goals. In addition, the linear programming analysis indicates which of the imposed restrictions are binding, i.e. prevent further increases in the value of the goal optimized.

It should be realized that the model results can not directly be compared to the actual situation. One of the major reasons is that optimum conditions are assumed, aimed at maximum goal achievement, contrary to 'real life' situations. Another important reason is that the defined production techniques are based on sustainable exploitation of the natural resources, which is currently not the case. Comparison of model results with the present situation is only relevant in relation to the question how a goal-oriented transition can be achieved from the current exhaustive mode of exploitation to one of the selected modes of sustainable exploitation. The differences between the present situation and the prospective one should provide indications for the necessary efforts.

The approach presented comprises a target-oriented analysis method (i.e. inputs are function of target yield) that allows explanatory analysis of the results in agro-technical terms. An input-oriented approach (yield is function of applied inputs), such as farming systems research, is seriously handicapped in explaining observed yields, which are the result of the specific combination of inputs, environmental and socio-economic conditions. In the approach presented here, however, important aspects of agricultural production systems can not be quantified (e.g. social and judicial aspects) and are thus excluded from the model analysis. Therefore, post-model analyses are required to examine the consequences of these omissions.

In addition to effects on crop yields, the impact of fertilizer availability was related to other agricultural activities and rural population. For the Fifth Region of Mali, the requirement for sustainability in terms of nutrients resulted in a strong interaction between crops and animal husbandry, because animal manure has to be maximally used. Furthermore, increased fertilizer availability resulted in a higher degree of diversification in both crop and animal husbandry activities. In addition, differences between the eleven agro-ecological zones were amplified.

Regional food needs can be met in normal years under the conditions of sustainability and an acceptable regional gross revenue. Surplus is produced in 7 of the 11 agro-ecological zones in the scenarios with restricted and intermediate inorganic fertilizer availability.

The post-model analysis indicated that scenario II, with intermediate inorganic fertilizer availability, is useful for exploring development options in view of the high population growth rate and the constraints on fertilizer supply. This scenario implies higher total imports of inorganic fertilizer, especially of phosphorus and potassium, and improved infrastructure. To stimulate the use of inorganic fertilizer, a reduction in farmgate price is recommended. Non-agricultural activities are required to generate additional regional gross revenue and reduce the dependence on animal husbandry, especially in view of the uncertain future of the meat market.

For a more elaborate post-model analysis, carried out in close cooperation with stakeholders in the region, inclusion of these non-agricultural activities in the IMGLP-model may be necessary.

PART B. DETAILED PLANT DATA

In this part, which gives an overview, only few comments are made about plant characteristics related to biomass distribution, fertilizer experiments and uptake of nutrients.

5. MILLET

5.1 Dry matter distribution

Results on dry matter distribution are presented as the probability curve of reported harvest indices (Figure 5.1) and on the basis of simulation results as the relation grain to straw (Figure 5.2).

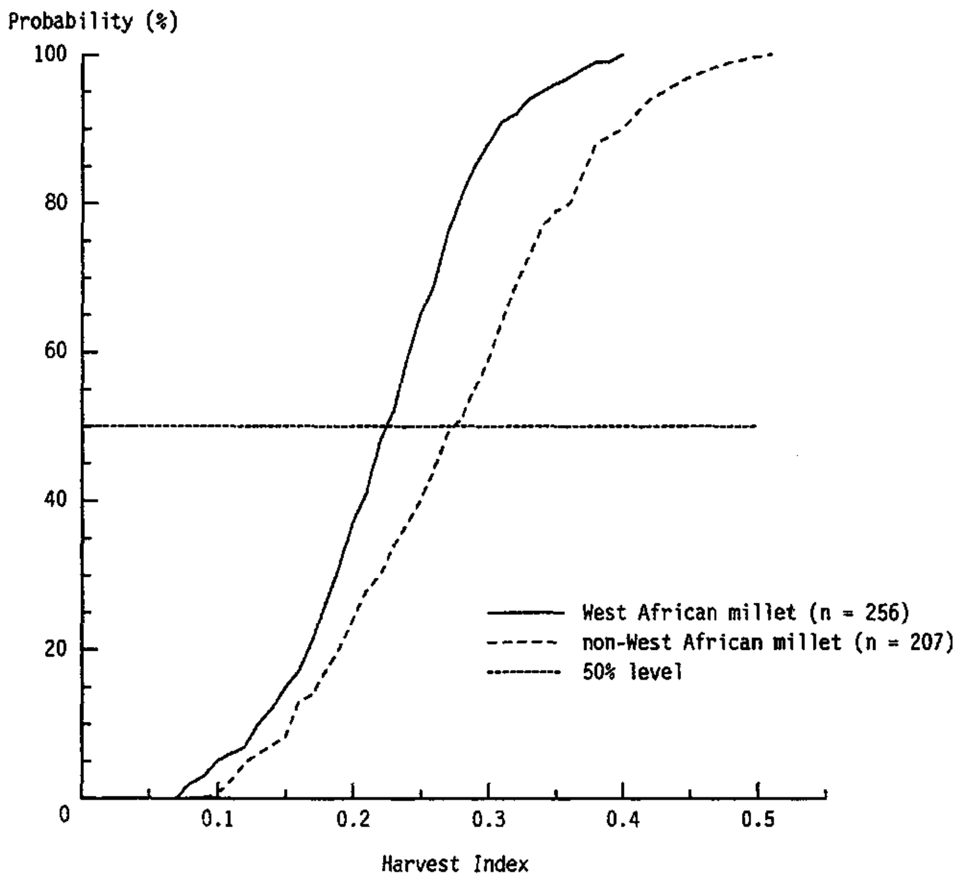


Figure 5.1. Harvest index distribution of millet under different conditions.

Sources West Africa: Balasubramanian & Nnadi, 1981; Bationo et al., 1991; Bertrand et al., 1972; Blondel, 1971a,b.; Christianson et al., 1990; Dancette, 1983; Duiker, 1989; van Duivenbooden & Cissé, 1989; Ganry, 1990; Ganry et al., 1974; Garba, 1990; Gosseye, pers. comm.; Hulet, 1988; ICRISAT, 1989; Jenny, 1974; Jones, 1976; Kassam & Stockinger, 1973; Ndiaye, 1978; Persaud et al., 1989; Pichot et al., 1974; Piéri, 1979; 1983; Sené, 1989; Siband, 1981; Sivakumar, 1990; Traoré, 1974; Vidal, 1963;

Elsewhere: Coaldrake & Pearson, 1985; Craufurd & Bidinger, 1988, 1989; Gautam et al., 1984; Giri & De, 1979; Gregory & Squire, 1979; Joshi, 1989; Lal, 1979; Prasad et al., 1985; Reddy et al., 1982; 1992; Sharma & Swarup, 1989; Singh & Randhawa, 1979; Wani et al., 1990;

Not included here, but for analysis of HI (Table 2.4) additionally used: Bationo & Mokwunye, 1991; Nabos et al., 1974; Muchow, 1989.

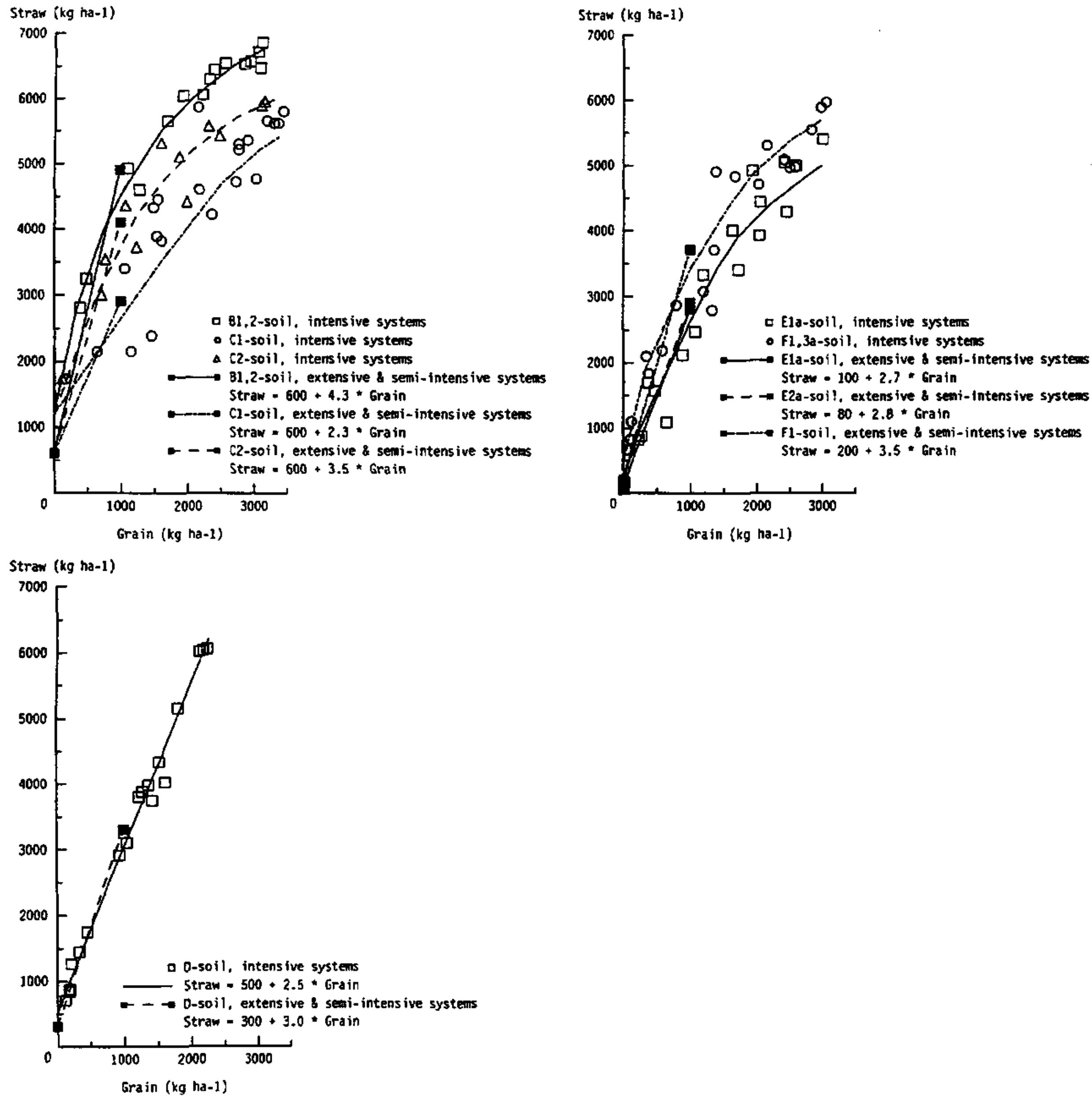


Figure 5.2. *Simulated relationship of millet straw and grain production for intensive production systems and estimated relationship for extensive and semi-intensive production systems (van Duivenbooden, 1991; Erenstein, 1990).*

5.2 Concentration of major elements

Table 5.1. *Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total above-ground biomass of millet at maturity; one line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
Mali	Souna	10.5	15.3	23.8	28.5	12.3	17.0	Gosseye, in prep
	Souna					7.7	16.0	Gosseye, in prep
	Souna			18.7	21.1			Yossi *ea*, 1991
	Souna			19.5	21.4			Yossi *ea*, 1991
	Souna			20.0	21.6			Yossi *ea*, 1991
	Ignadi			18.6	20.3			Yossi *ea*, 1991
	Ignadi			18.9	20.2			Yossi *ea*, 1991
	Ignadi			19.8	21.1			Yossi *ea*, 1991
	P-fert.exp.	3.0	5.5	17.5	20.0	4.3	7.0	Jenny, 1974
	P-fert.exp.	3.9	10.2	14.5	20.2	5.6	11.9	Jenny, 1974
	P-fert.exp.	2.6	4.2	15.4	19.0	3.5	5.0	Jenny, 1974
	Niou Bobo	2.4	3.6	13.8	17.5	5.1	6.6	Traoré, 1974
Niger	HKN 1971	3.8	5.0	17.5	21.3	6.9	9.8	Pichot *ea*, 1974
	P3 Kolo 1972	10.8	15.7	20.9	28.1	12.6	17.2	Pichot *ea*, 1974
	P3 Kolo 1973	3.5	10.3	16.0	24.5	6.5	13.6	Pichot *ea*, 1974
			10.2		20.4		12.8	Bertrand *ea*, 1972
		7.1	8.0	17.2	17.3			Bationo &
								Mokwunye, 1991
Nigeria	Gero			13.3	16.5			Sing & Thakare,
	Dwarf			13.1	15.8			1986
	Gero early			15.7	17.0			Sing &
	Hybrid			14.7	16.2			Thakare,
	Ex-Borna			14.2	20.0			1986
	HKP	2.4	4.3	13.2	15.2			Reddy *ea*, 1992
	HKP	5.4	5.8	14.3	15.4			Reddy *ea*, 1992
Senegal		6.4		12.9				Ganry, 1990
		9.1		21.3		12.2		Ganry, 1990
				15.9	21.3			Ganry, 1990
	Souna III			12.8	19.5			Ganry *ea*, 1974
	Souna III	9.7	9.9	20.8	23.3			van Duivenbooden
								& Cissé, 1989
	Souna III			17.5-25.2				van Duivenbooden
								& Cissé, unpubl.
	Souna III					8.8	8.9	Cissé, 1988
	Souna III	4.1	7.5	15.9	22.0			Piéri, 1979
	Souna III			12.9	22.2			Ndiaye, 1978
	Improved			13.1	18.3			Ndiaye, 1978
	Various	4.4	6.1	14.5	16.6	6.2	8.0	Blondel, 1971a
	Sanio			10.4	19.5			Charreau & Vidal,
			-					1965
					19.0			Tourte *ea*, 1971
	pot exp.	4.4	8.0	9.6	14.8			Ganry *ea*, 1978
						10.3	10.6	Piéri, 1985; 1983

.../...

Table 5.1. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
General		9.0		19.8				RFMC, 1980
General				17.3				Euroconsult, 1989
India	BK560	5.7	6.5	16.3	18.3	6.8	7.9	Sharma & Swarup, 1989
	various	4.6	7.6	14.1	17.0			Wani *ea*, 1990
		5.5	7.9	18.0	23.4			Lal, 1979
Phosphorus								
Mali	Souna	0.6	0.7	2.5	3.8	0.8	1.1	Gosseye, in prep
	Souna	0.4	0.7					Gosseye, in prep
	P-fert.exp.	0.5	0.7	2.5	3.4	0.6	0.8	Jenny, 1974
	P-fert.exp.	0.3	0.7	2.2	3.5	0.5	1.0	Jenny, 1974
	P-fert.exp.	0.4	0.7	1.9	3.2	0.7	1.3	Jenny, 1974
		0.3	0.7	2.5	3.0	0.7	1.1	Traoré, 1974
Niger	HKN 1971	2.2	3.9	3.8	4.3	2.6	4.0	Pichot *ea*, 1974
	P3 Kolo 1972	0.5	0.7	3.0	3.6	0.9	1.1	Pichot *ea*, 1974
	P3 Kolo 1971	0.6	0.9	2.6	3.4	1.1	1.6	Nabos *ea*, 1974
	P3 Kolo 1970	0.6	1.0	2.2	2.4	1.2	1.6	Nabos *ea*, 1974
	P3 Kolo 1969	0.7	1.0	1.7	2.7	0.9	1.5	Nabos *ea*, 1974
			0.7	2.4			1.1	Bertrand ea, 1972
		0.3		1.8	2.5			Bationo & Mokwunye, 1991
Senegal	Souna III	0.6	1.1	3.1	3.2			van Duivenbooden & Cissé, 1989
	Souna III	1.3	1.4	2.7	3.0			van Duivenbooden & Cissé, unpl.
	Souna III					1.2	1.6	Cissé, 1988
	Souna III	0.5	1.7	3.1	3.8			Piéri, 1979
	Souna III			2.3	2.4			Ganry *ea*, 1974
	Souna III			2.3	3.8			Ndiaye, 1978
	Improved			2.7	3.9			Ndiaye, 1978
						1.3	1.4	Piéri, 1985; 1983
					4.4			Tourte *ea*, 1971
			1.8					Richard *ea*, 1989
General		1.4		3.6				RFMC, 1980
India	BK560	1.4	1.7	3.3	3.9	1.6	2.0	Sharma & Swarup, 1989
	various	1.0	1.5	3.3	3.7	1.9	2.2	Wani *ea*, 1990
	HB4					1.0	1.1	Lal, 1979
Potassium								
Mali	P-fert.exp.	11.6	13.3	4.4	5.3	11.1	12.7	Jenny, 1974
	P-fert.exp.	11.1	16.3	4.5	5.4	10.6	14.7	Jenny, 1974
	P-fert.exp.	16.8	21.4	3.9	5.1	14.8	18.1	Jenny, 1974
	Niou Bobo			4.6	5.2			Traoré, 1974
Niger	HKN 1971	24.4	34.1	6.0	6.7	20.4	26.3	Pichot *ea*, 1974
	P3 Kolo 1972	21.6	31.8	4.6	5.2	19.4	28.4	Pichot *ea*, 1974
		19.8		4.3		15.7		Bertrand ea, 1972
		14.0	17.7	4.4	4.8			Bationo & Mokwunye, 1991

.../...

Table 5.1. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Potassium								
Nigeria		23.3	24.0	3.3	3.3			Jones, 1976
Senegal	Souna III	17.0	23.0	4.0	4.2			van Duivenbooden & Cissé, 1989
	Souna III			3.8	4.7			van Duivenbooden & Cissé, unpubl.
	Souna III					11.3	16.8	Cissé, 1988
	Souna III	7.3	26.0	2.8	4.4			Piéri, 1979
	Souna III			3.1	5.3			Ndiaye, 1978
	Improved			3.7	4.8			Ndiaye, 1978
Senegal		10.0	24.5					Piéri, 1985; 1983
						10.0	10.2	Piéri, 1985; 1983
					9.1			Tourte *ea*, 1971
India	BK560	15.9	18.1	3.4	3.5	14.7	16.3	Sharma & Swarup, 1989
	various	20.7	28.7	4.6	5.1	15.1	18.9	Wani *ea*, 1990
	HB4					10.6	13.8	Lal, 1979
Calcium								
Mali	P-fert.exp.	2.0	3.8	0.1	0.2	1.7	3.2	Jenny, 1974
	P-fert.exp.	0.9	1.3	0.2	0.4	0.8	1.2	Jenny, 1974
	Niou Bobo	1.6	2.5	0.3	0.4	1.4	2.0	Traoré, 1974
Niger	HKN 1971	2.1	3.3	0.2	0.3	1.6	2.5	Pichot *ea*, 1974
	P3 Kolo 1972	4.9	5.3	0.4	0.6	4.4	4.6	Pichot *ea*, 1974
			3.2		0.2		2.4	Bertrand *ea*, 1972
						2.8	3.0	Piéri, 1983; 1985
		0.9	3.9	0.3	1.4			Bationo & Mokwunye, 1991
Nigeria		2.8	2.9	0.1				Jones, 1976
Senegal	Souna III	2.2	4.2					van Duivenbooden & Cissé, 1989
	Souna III	3.0	5.4	0.7	3.0			Piéri, 1979
	Souna III			0.9	2.1			Ndiaye, 1978
	Improved			0.7	1.4			Ndiaye, 1978
					1.9			Tourte *ea*, 1971
		3.1						Richard *ea*, 1989
General			5.5		4.0			RFMC, 1980
Magnesium								
Mali	P-fert.exp.	1.8	3.0	0.8	1.3	1.7	2.6	Jenny, 1974
	P-fert.exp.	1.1	1.6	1.0	1.3	1.1	1.6	Jenny, 1974
	Niou Bobo	0.8	1.1	0.8	1.1	1.3	1.9	Traoré, 1974
Niger	HKN 1971	3.8	4.3	1.4	1.6	3.1	3.6	Pichot *ea*, 1974
	P3 Kolo 1972	5.9	6.9	1.2	1.4	5.4	6.4	Pichot *ea*, 1974
			3.7		1.1		3.1	Bertrand ea, 1972
						4.8	5.3	Piéri, 1983; 1985
		2.1	2.5	1.3	1.5			Bationo & Mokwunye, 1991
Nigeria		2.5	2.8	1.0	1.0			Jones, 1976
Senegal	Souna III	4.1	5.2	1.2	1.3			van Duivenbooden & Cissé, 1989

.../...

Table 5.1. Continued.

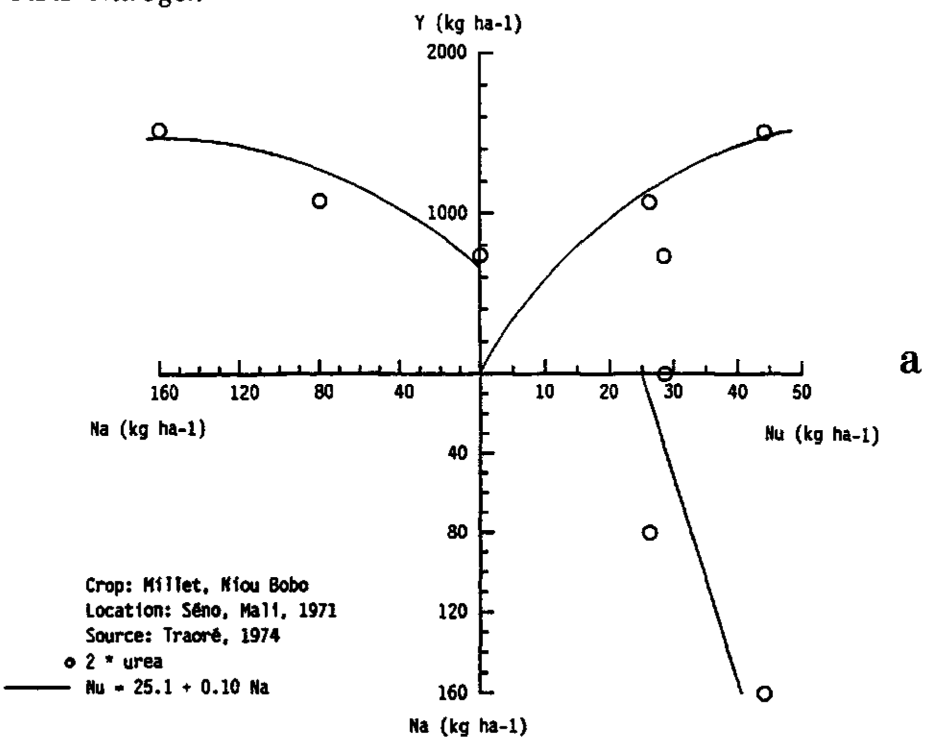
COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Magnesium								
Senegal	Souna III	2.3	4.4	1.1	1.3			Piéri, 1979
	Souna III			0.9	1.1			Ndiaye, 1978
	Improved			0.9	1.3			Ndiaye, 1978
			4.4					Richard *ea*, 1989
	leaf blades		5.4					Richard *ea*, 1989
Sulphur								
Mali	P-fert.exp.	0.7	1.4	1.0	1.6	0.8	1.4	Jenny, 1974
	P-fert.exp.	1.4	2.3	0.8	1.4	1.3	2.2	Jenny, 1974
	Niou Bobo	0.4	0.6	0.8	1.1	0.5	0.7	Traoré, 1974
Niger	HKN 1971	1.7	2.4	1.4	2.0	1.8	2.2	Pichot *ea*, 1974
	P3 Kolo 1972	0.8	1.2	1.0	2.2	0.9	1.3	Pichot *ea*, 1974
			3.2		1.9		2.9	Bertrand ea, 1972
Senegal	Souna III	0.8		1.1				Piéri, 1979
Sodium								
Senegal		0.2						Richard *ea*, 1989
India		0.8	1.2	0.3	0.4			Sharma & Swarup, 1989

With respect to the data in Table 5.1, the following remarks may be made. P-concentrations of 2.2 to 2.9 g kg^{-1} reported for straw of HKN (Pichot *et al.*, 1974) are considered measurement errors, as they are about a factor ten higher than other reported values.

The K-concentration of straw of 7.3 g kg^{-1} (Piéri, 1979) is, in comparison with other reported values, considered too low. Hence, the nearest minimum value, i.e. 10.0 is taken as minimum (Piéri, 1979; 1985).

5.3 Three quandrant figures

5.3.1 Nitrogen



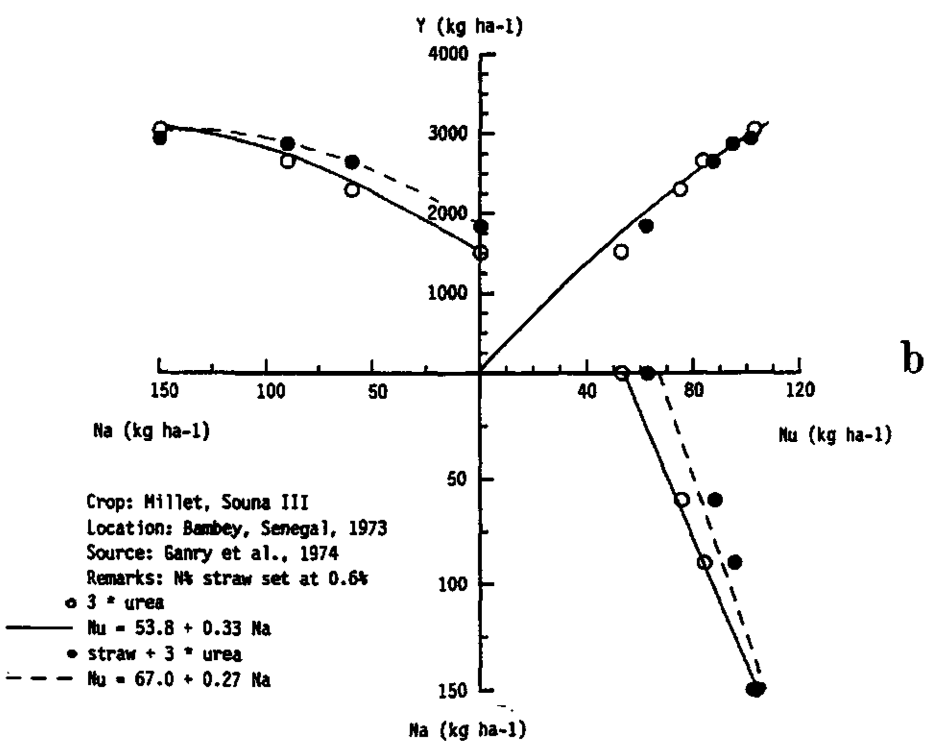


Figure 5.3. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield.*

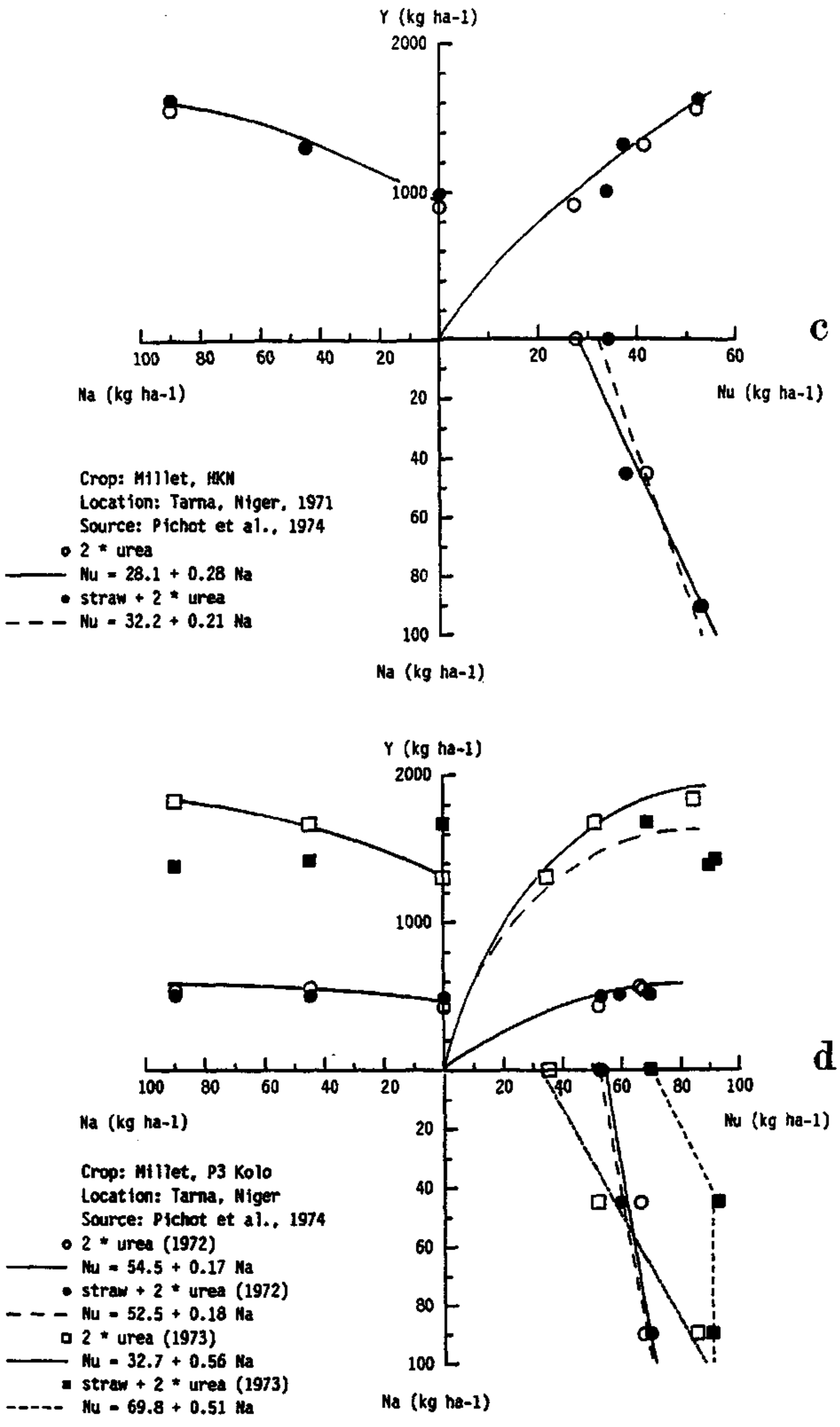


Figure 5.3. Continued.

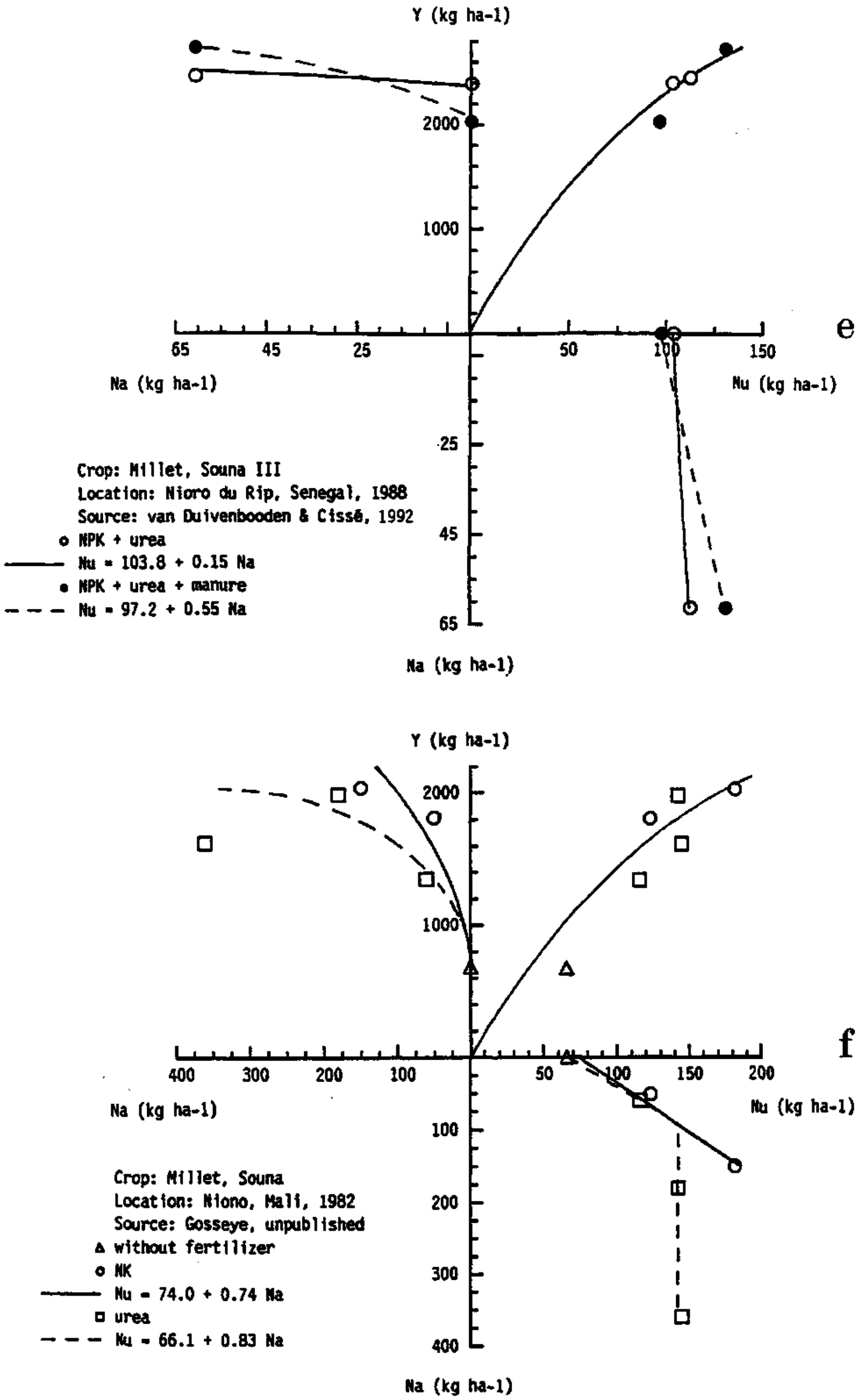
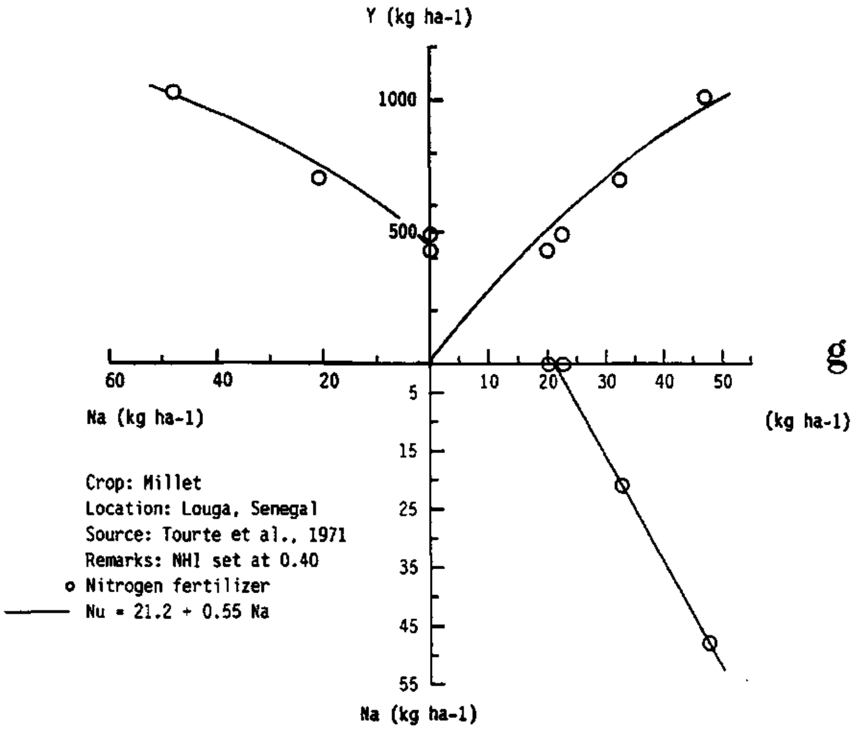


Figure 5.3. Continued.



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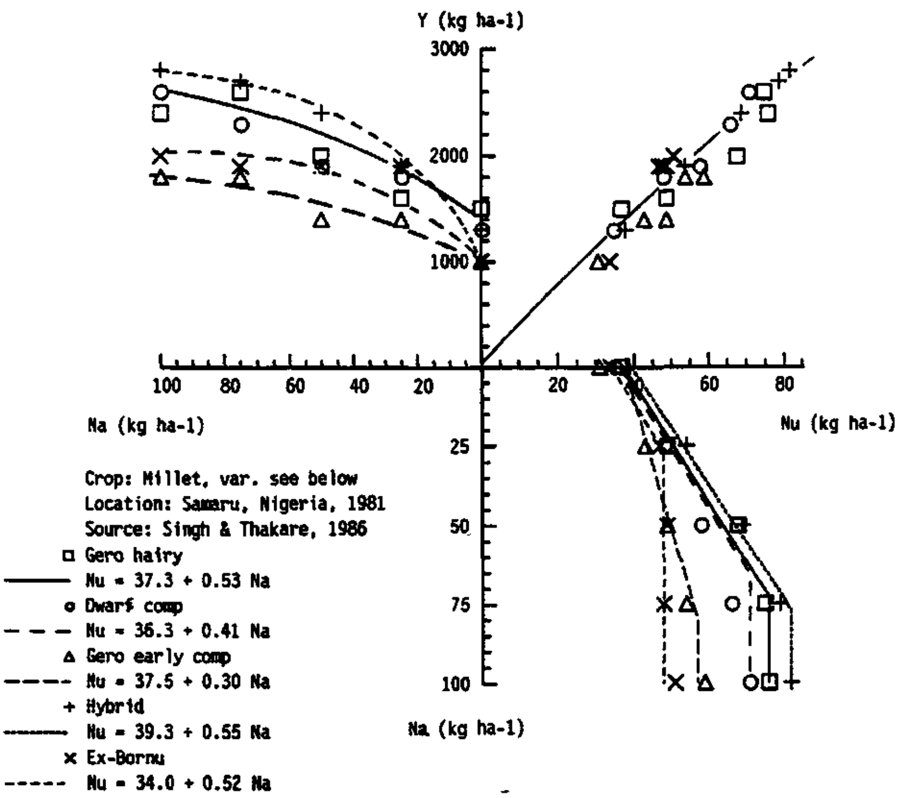

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Figure 5.3. Continued.

5.3.2 Phosphorus

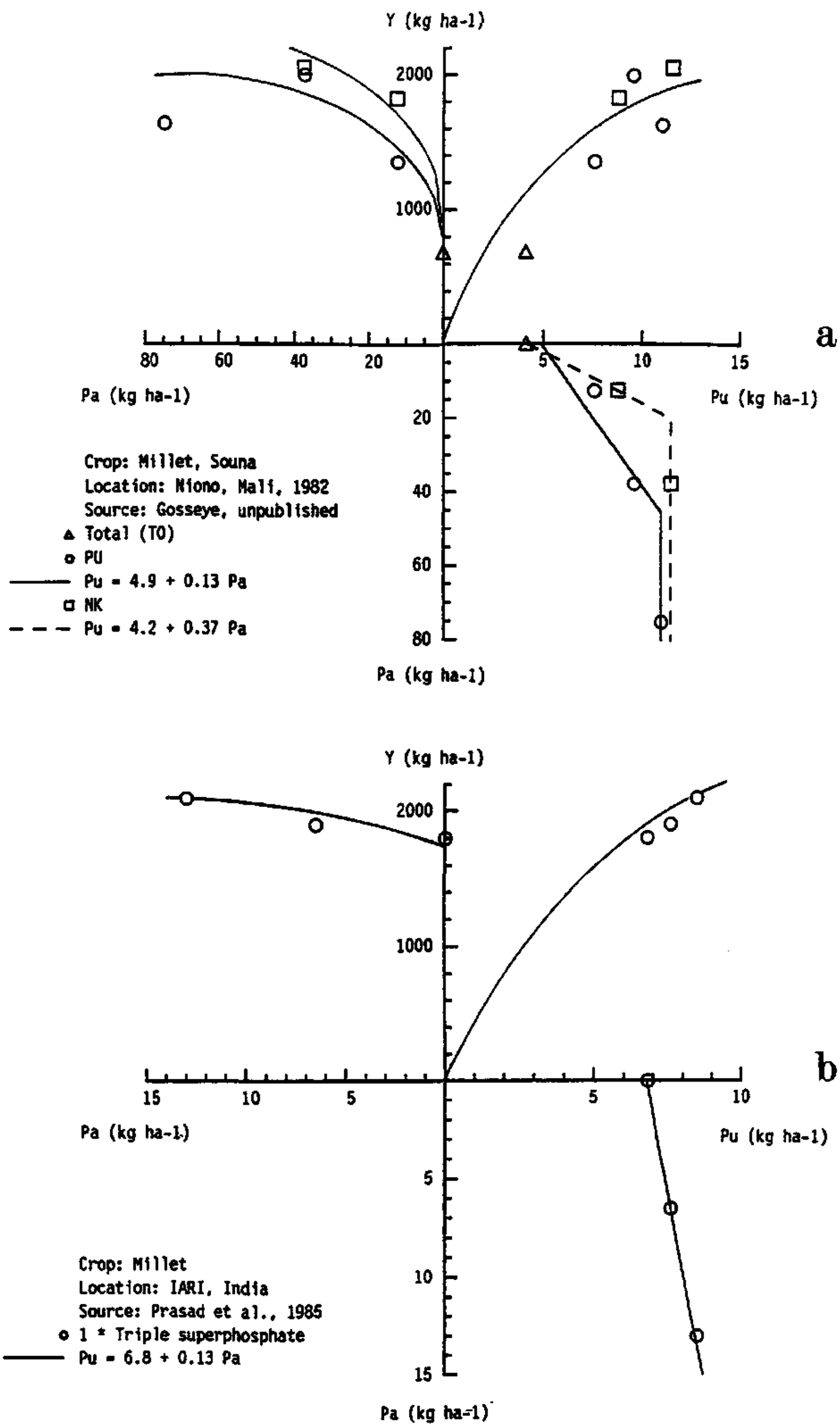


Figure 5.4. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*

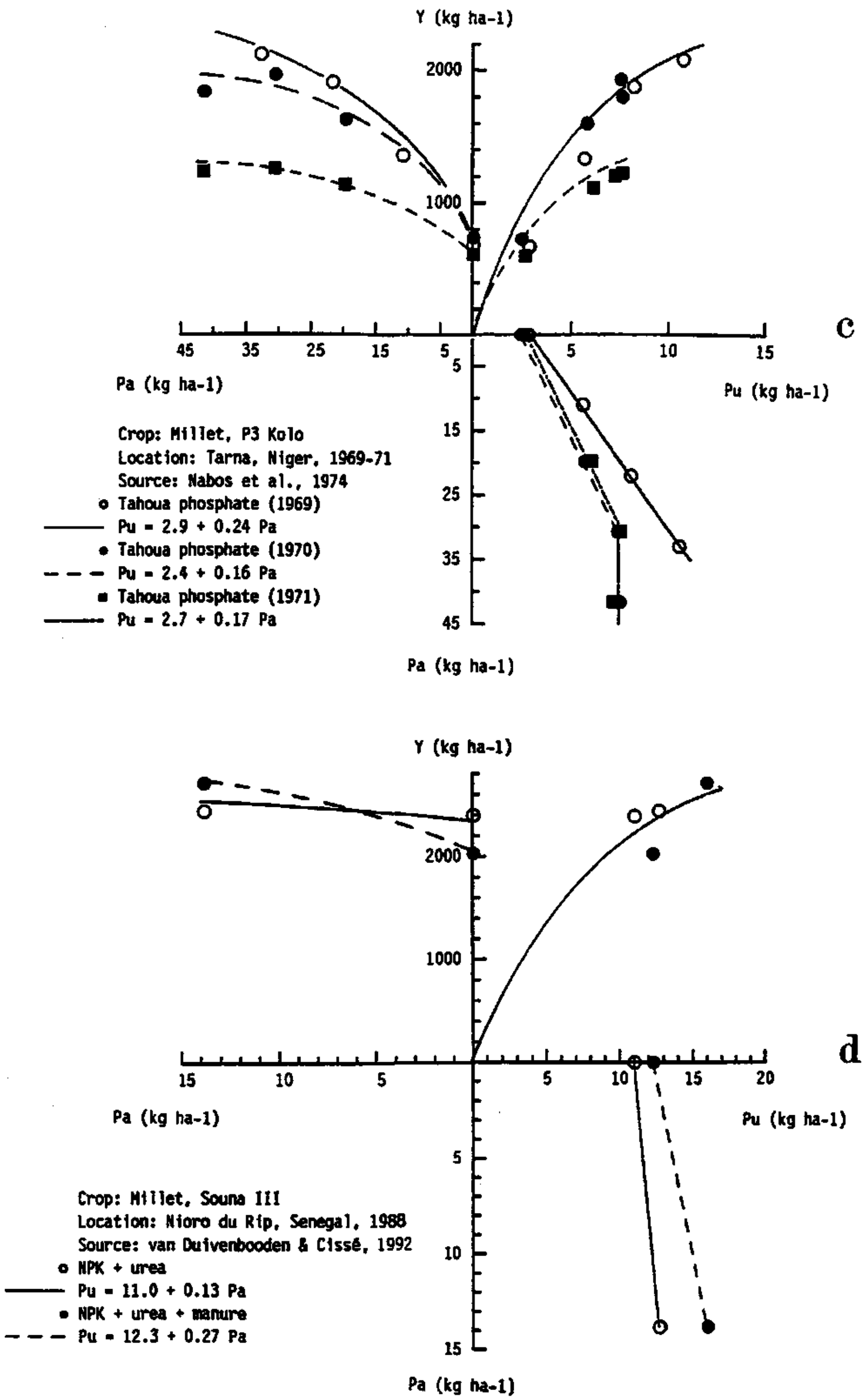


Figure 5.4. Continued.

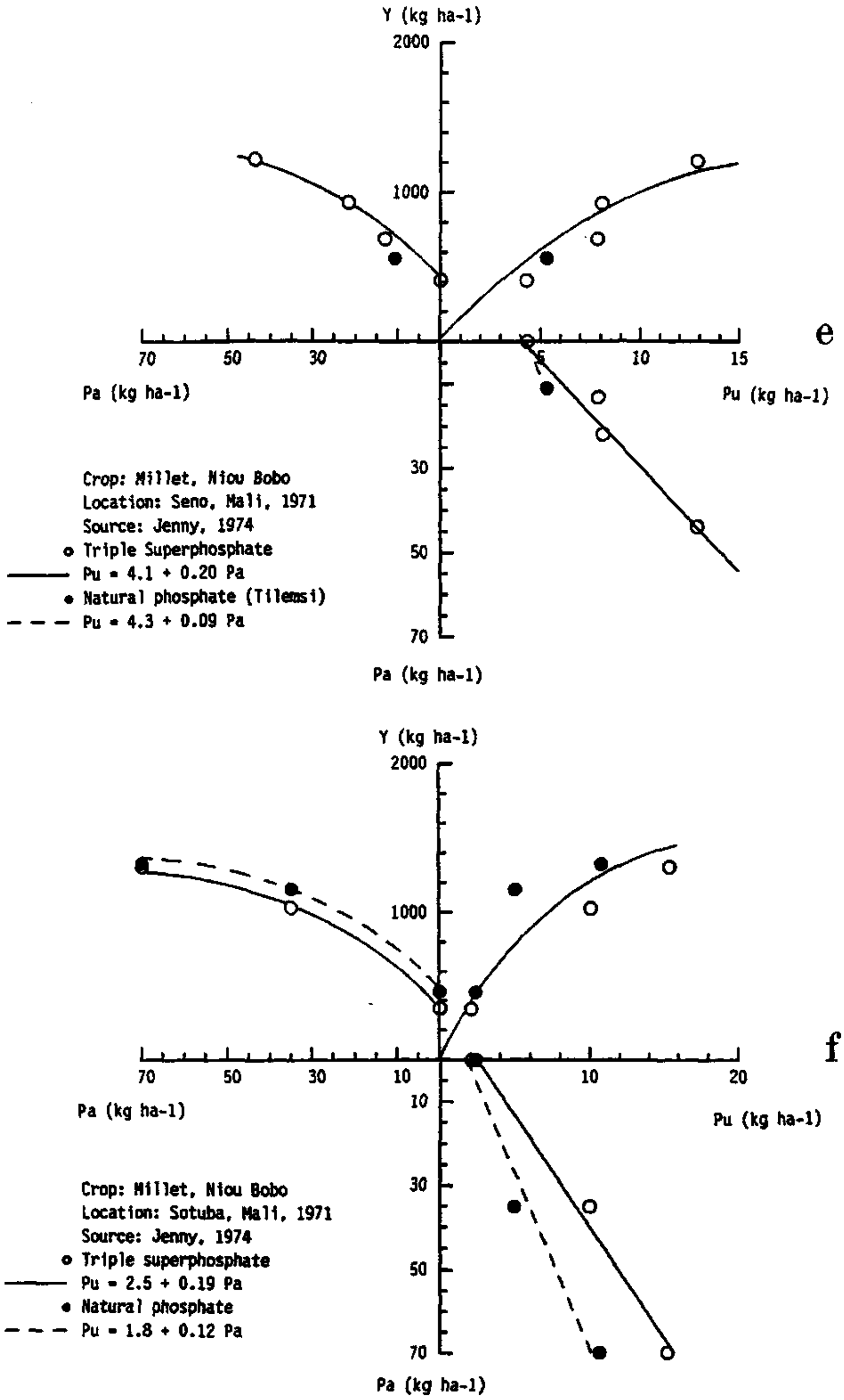


Figure 5.4. Continued.

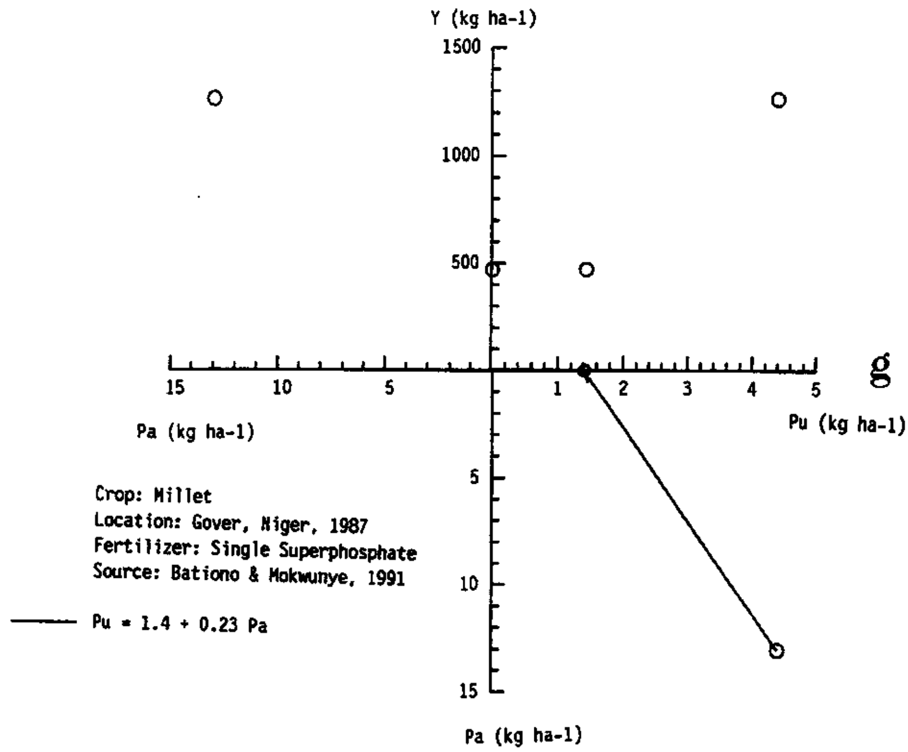


Figure 5.4. Continued.

5.3.3 Potassium

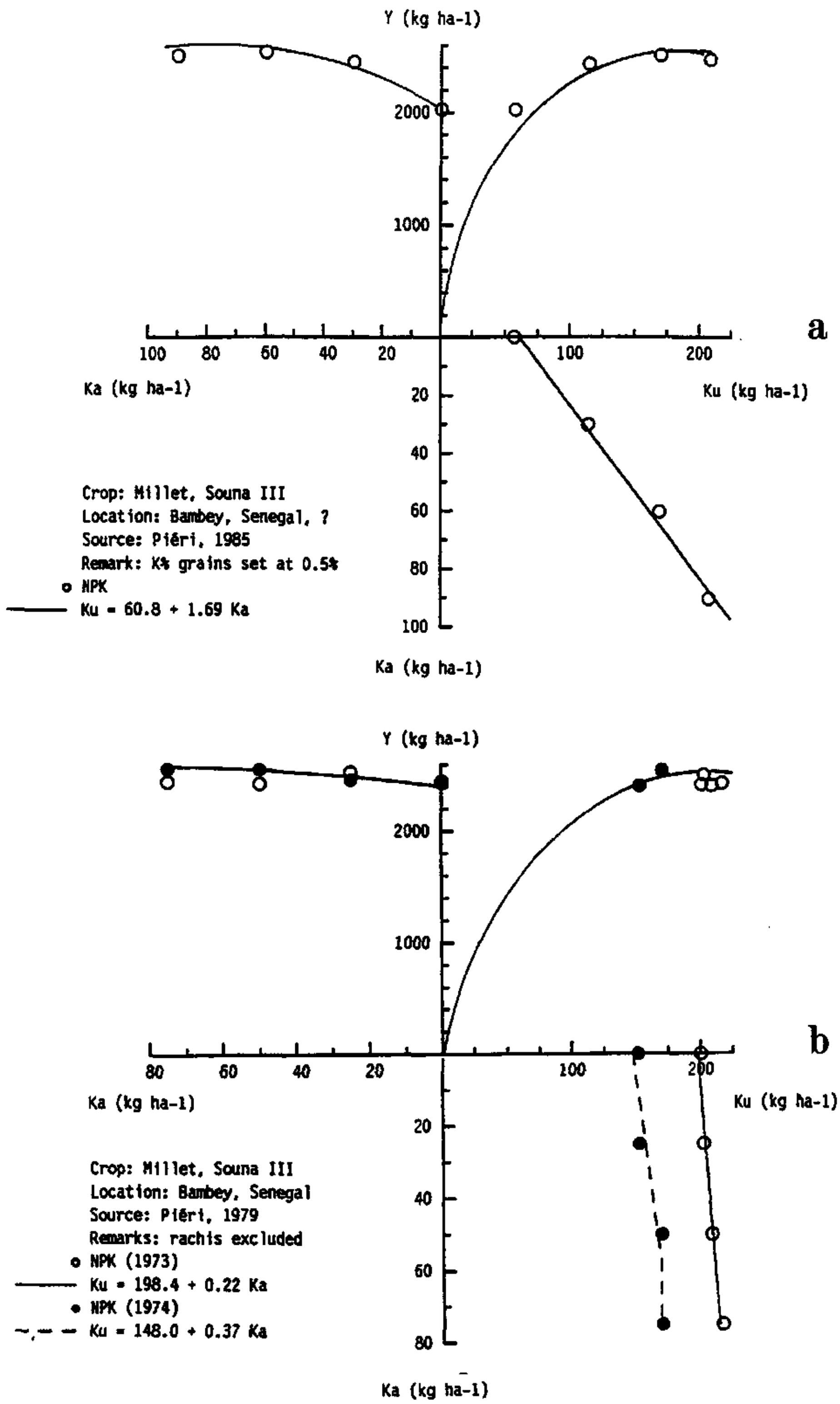
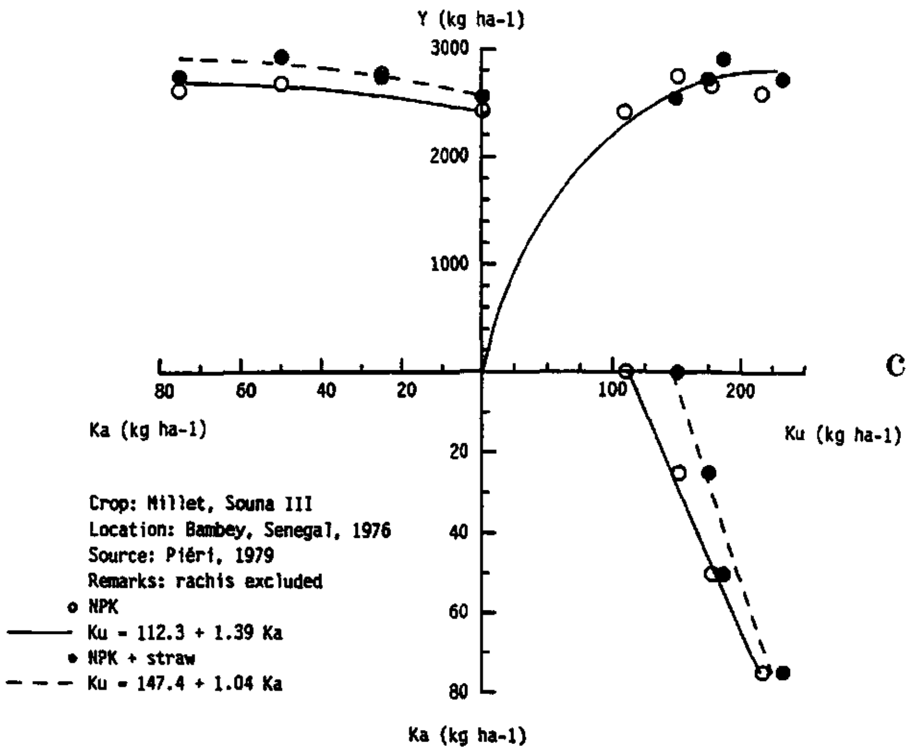


Figure 5.5. *Relation between total potassium content (K_u) and yield (Y), that between potassium application (K_a) and potassium content, and that between potassium application and yield.*



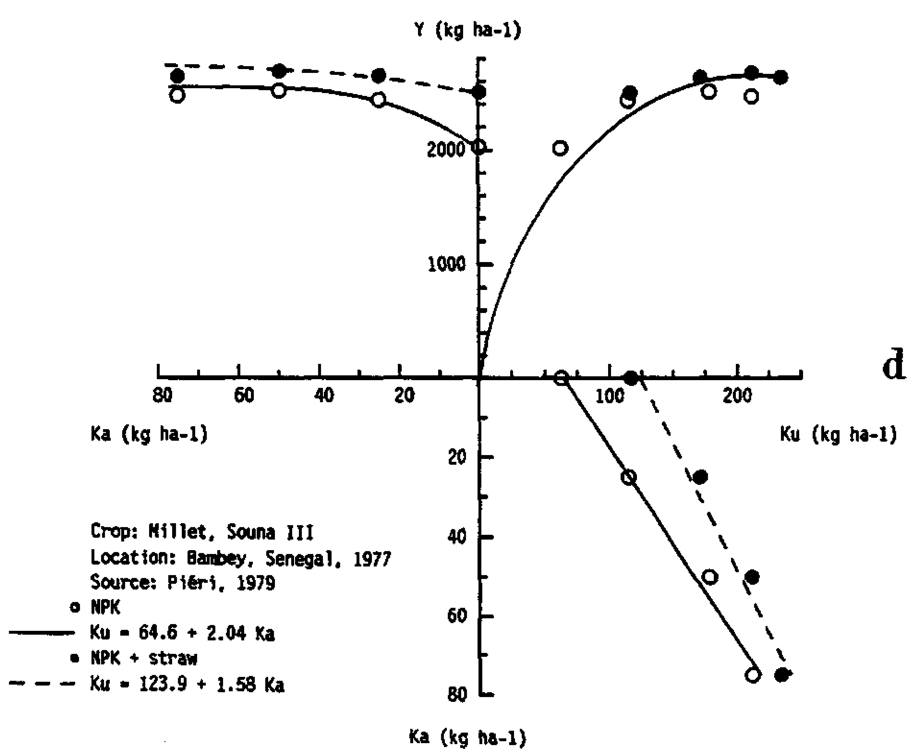
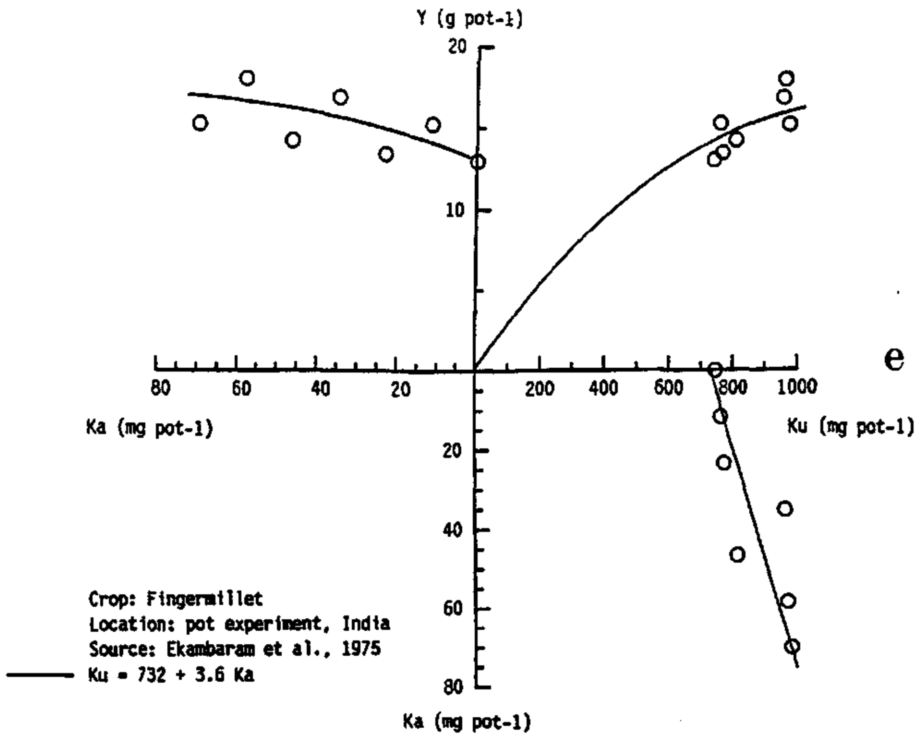


Figure 5.5. Continued.



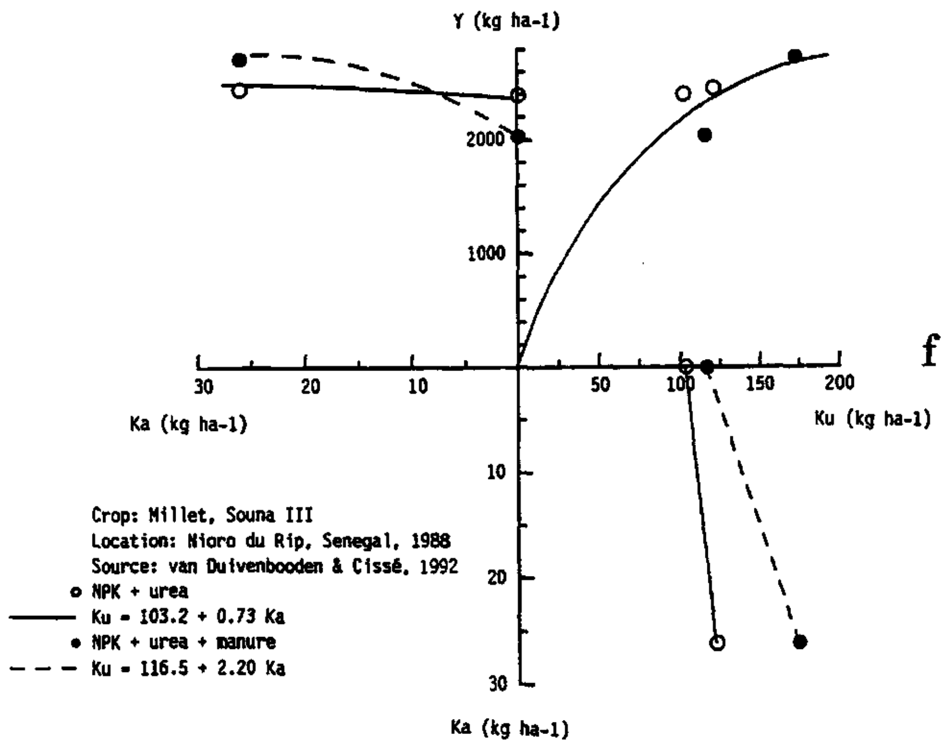


Figure 5.5. Continued.

5.4 Nutrient content as related to yield

The relationship yield/N-content in millet is more or less identical in India and West Africa. However, the initial slope (YNI) is somewhat higher in India than in West Africa, especially if compared to the one for Senegal, 45 versus 35 kg kg^{-1} (Figure 5.6c and a, respectively). The value of other West African countries is in between (Figure 5.6b).

General causes for variation in reported Y/N_u values have been discussed in Section 2.4. In addition, with respect to millet in Senegal, is that N_u in the data reported by Piéri (1979) did not included N-content in the rachis, but as that did not exceed 10% of the total in the experiment of van Duivenbooden & Cissé (1989), even after correction, those points exhibit a higher ratio Y/N_u. As Ganry *et al.* (1974) did not report N-contents in straw of millet, that was set at the generally observed value of 0.6%.

From available data (Piéri, 1979) with respect to effects of other nutrients on the relationship Y/N_u, it is concluded that K-fertilizer application has no effects.

In the relationship yield/P-content, as for nitrogen, differences occur between West Africa and India (Figure 5.7). The difference in both relationships is mainly caused by a higher harvest index in millet in India, 0.28 versus 0.22 (Figure 5.2).

Additional values are available, but as the growing conditions (under flooding; Sharma & Swarup, 1989) differs from those reported by other authors, they are not included. The available data for proso millet (Rodriquez *et al.*, 1990) are also not included.

For a further discussion on millet and nutrient uptake in Senegal, reference is made to van Duivenbooden & Cissé (1992).

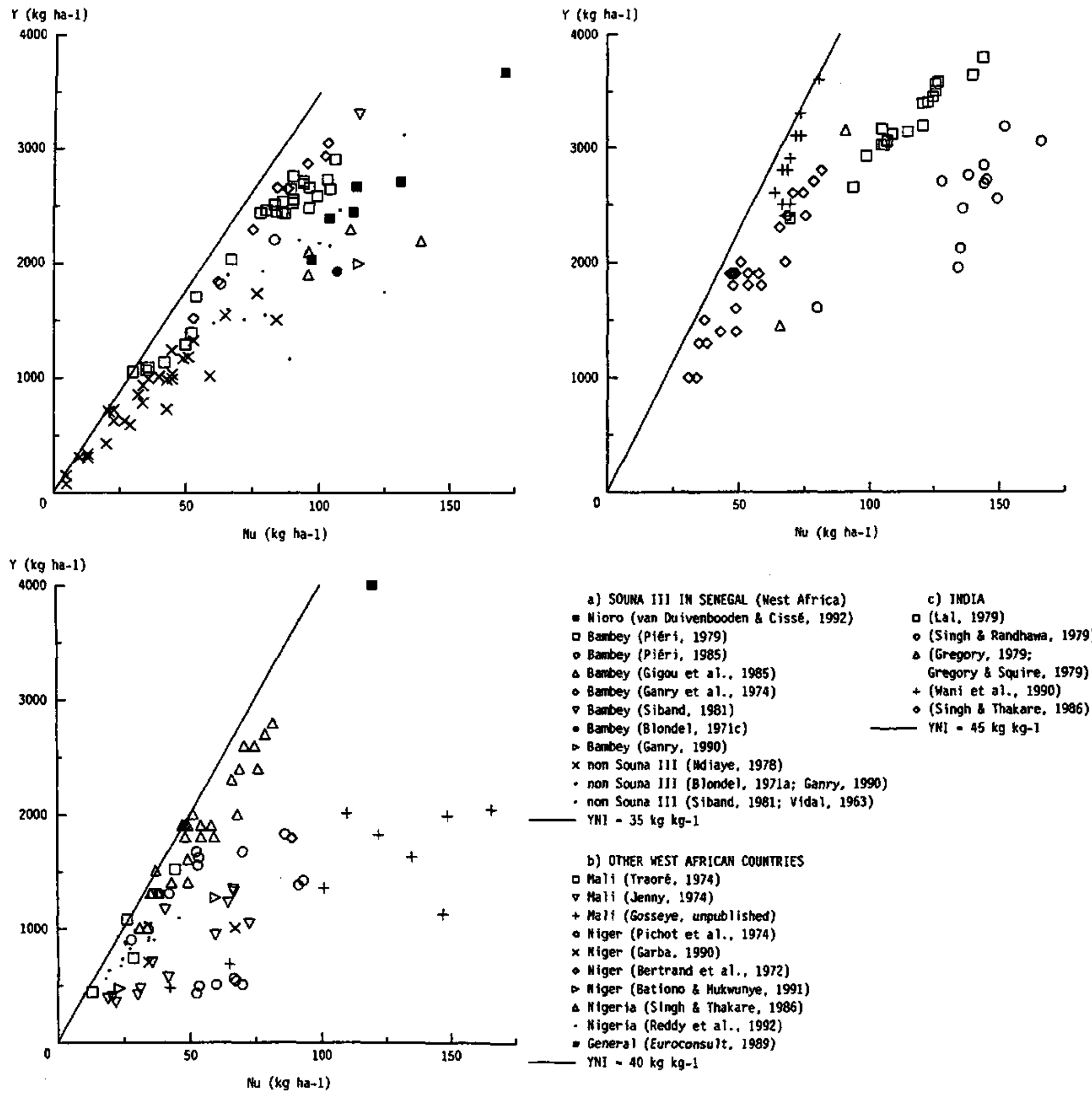


Figure 5.6. *Relation between total nitrogen content (N_u) and yield (Y) of millet; YNI = initial slope.*

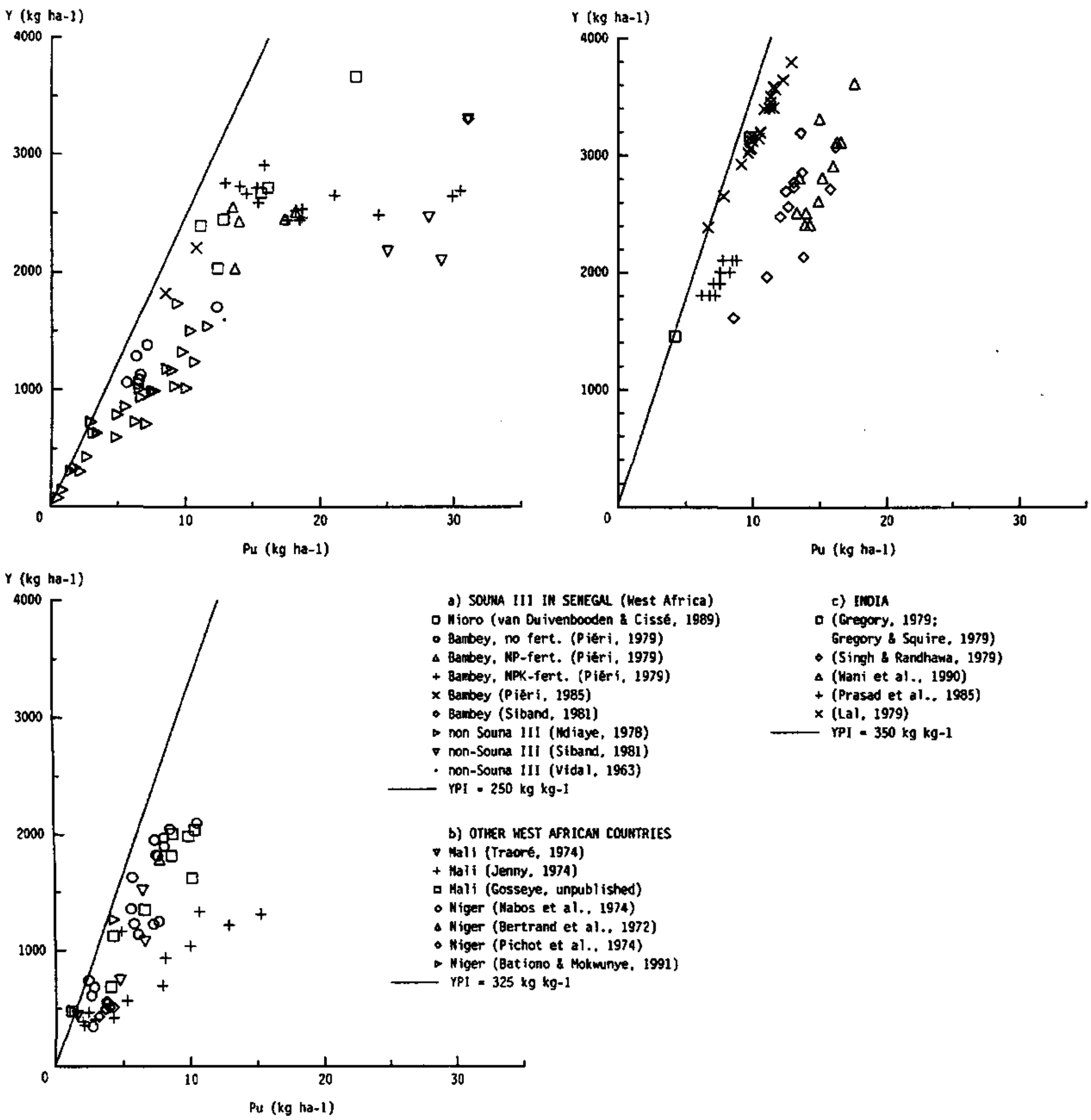


Figure 5.7. *Relation between total phosphorus content (P_u) and yield (Y) of millet. YPI = initial slope.*

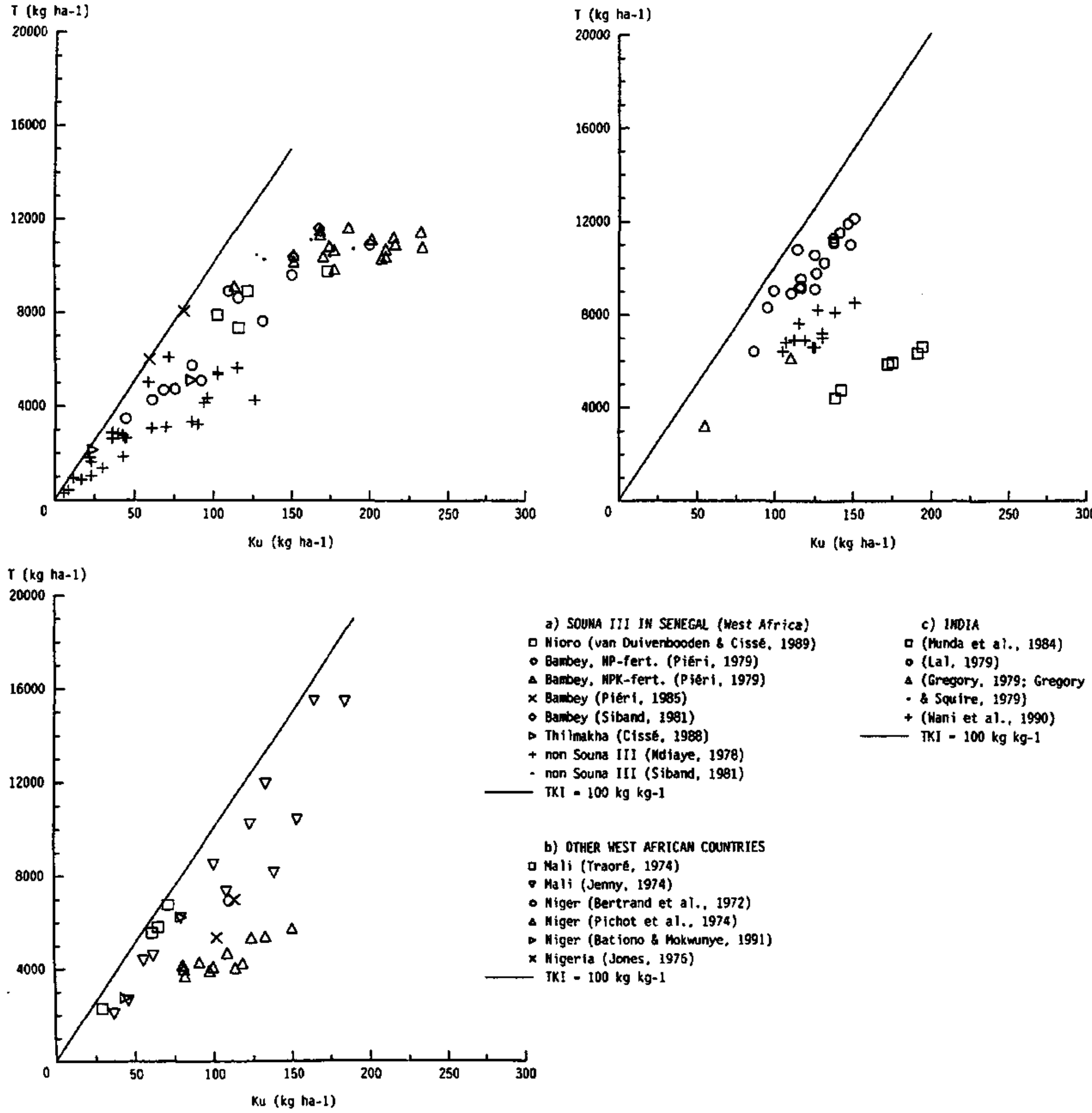


Figure 5.8. *Relation between total potassium content (K_u) and total above-ground dry matter (T) of millet. TKI = initial slope.*

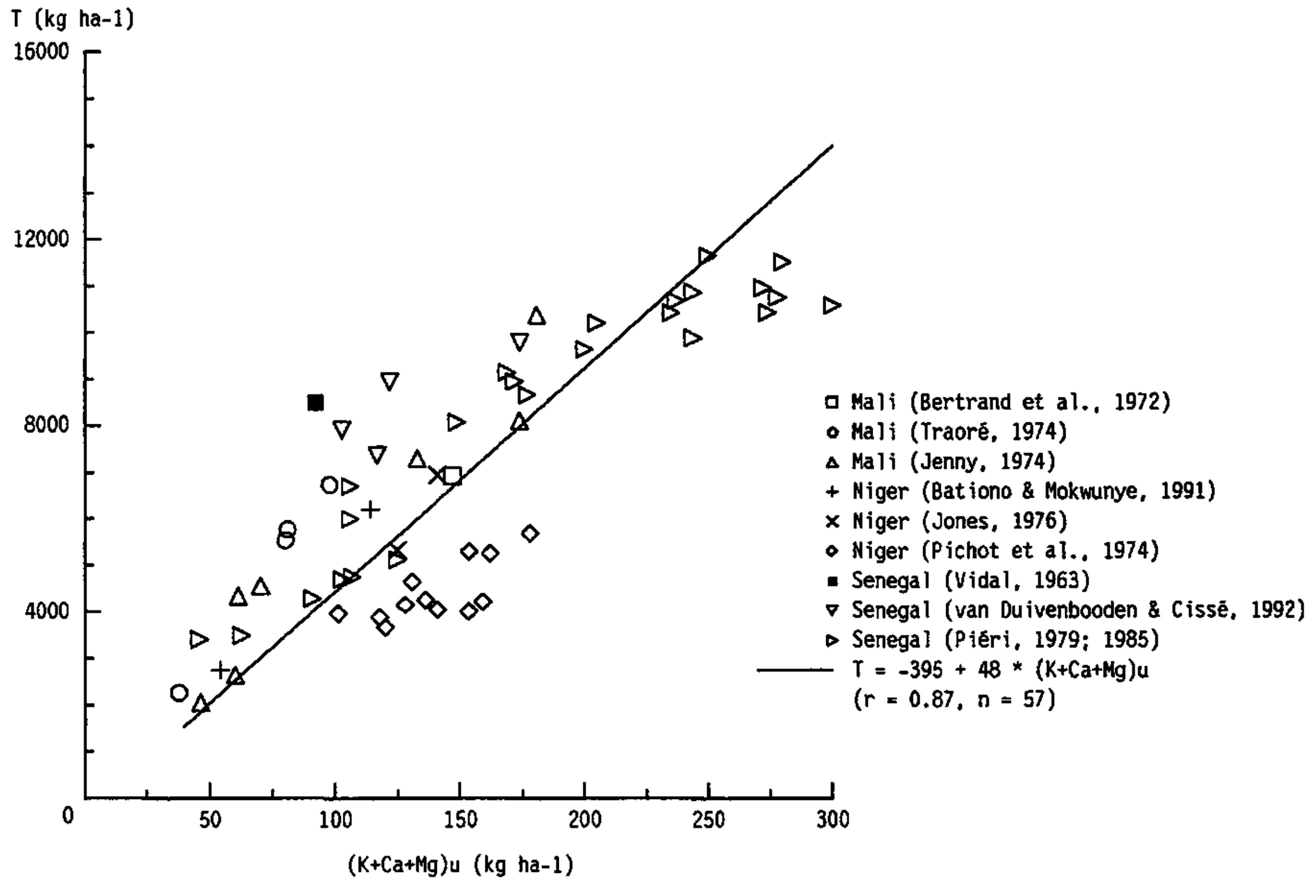


Figure 5.9. *Relation between the combined content of potassium, calcium and magnesium $(K+Ca+Mg)_u$ and total above-ground dry matter (T) in millet. Line represents average regression line.*

5.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 5.10; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

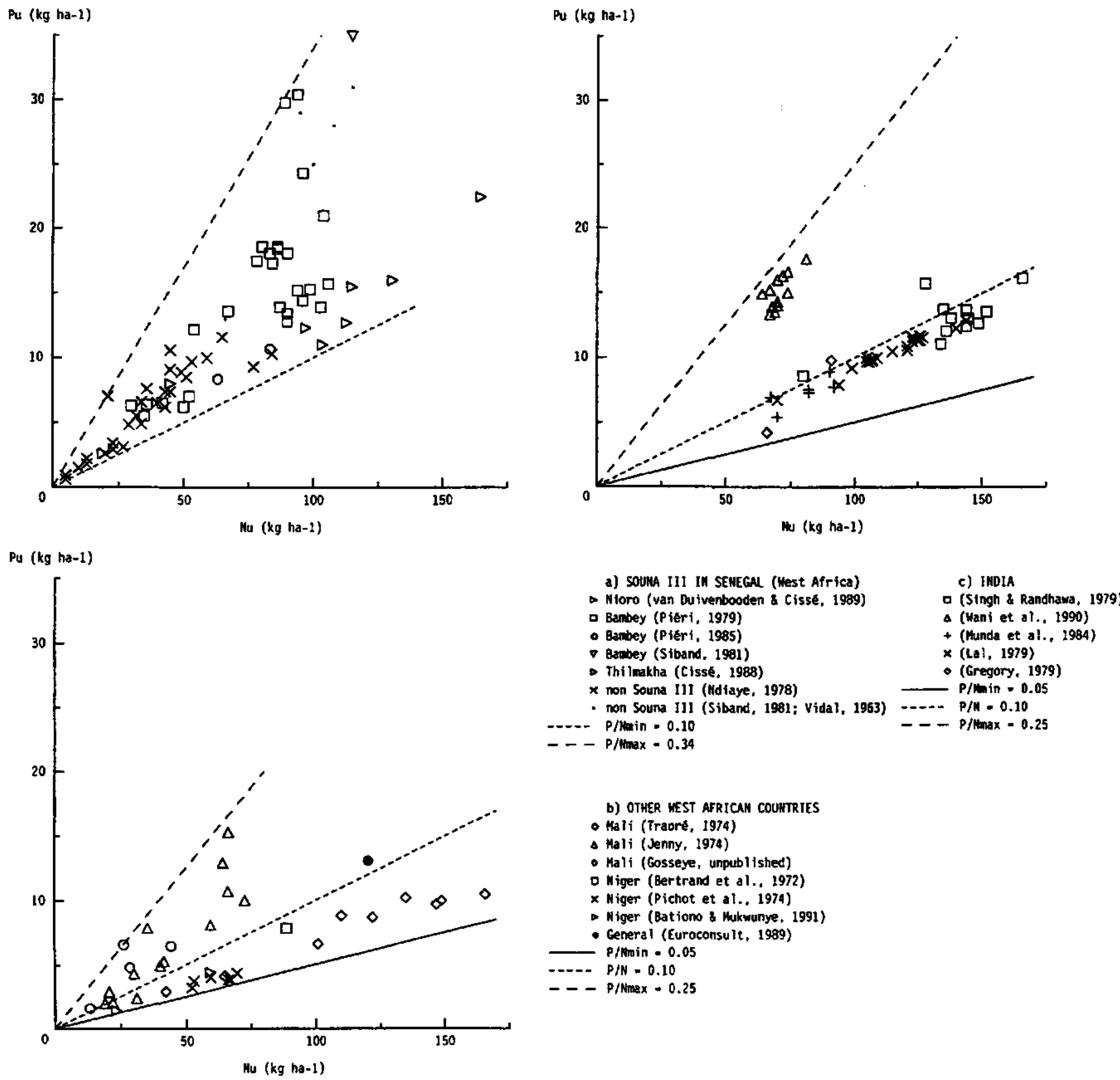


Figure 5.10. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of millet.*

5.6 Relations among relative post-anthesis nutrient uptake values of N, P and K

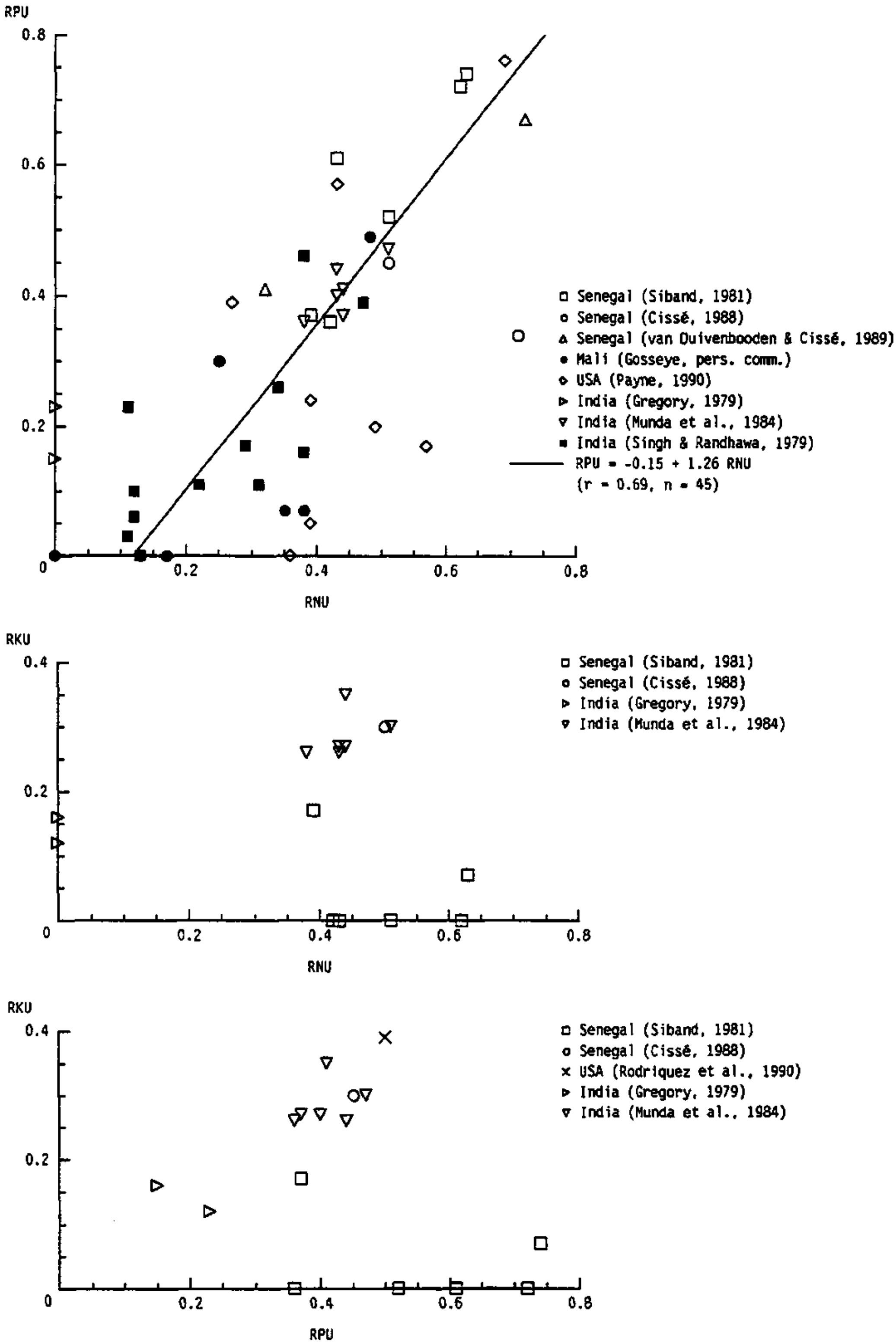


Figure 5.11. *Relationship between relative post-anthesis nutrient uptake in millet of a) nitrogen and phosphorus, b) nitrogen and potassium and c) phosphorus and potassium. Line represents average regression line.*

5.7 Nutrient harvest indices

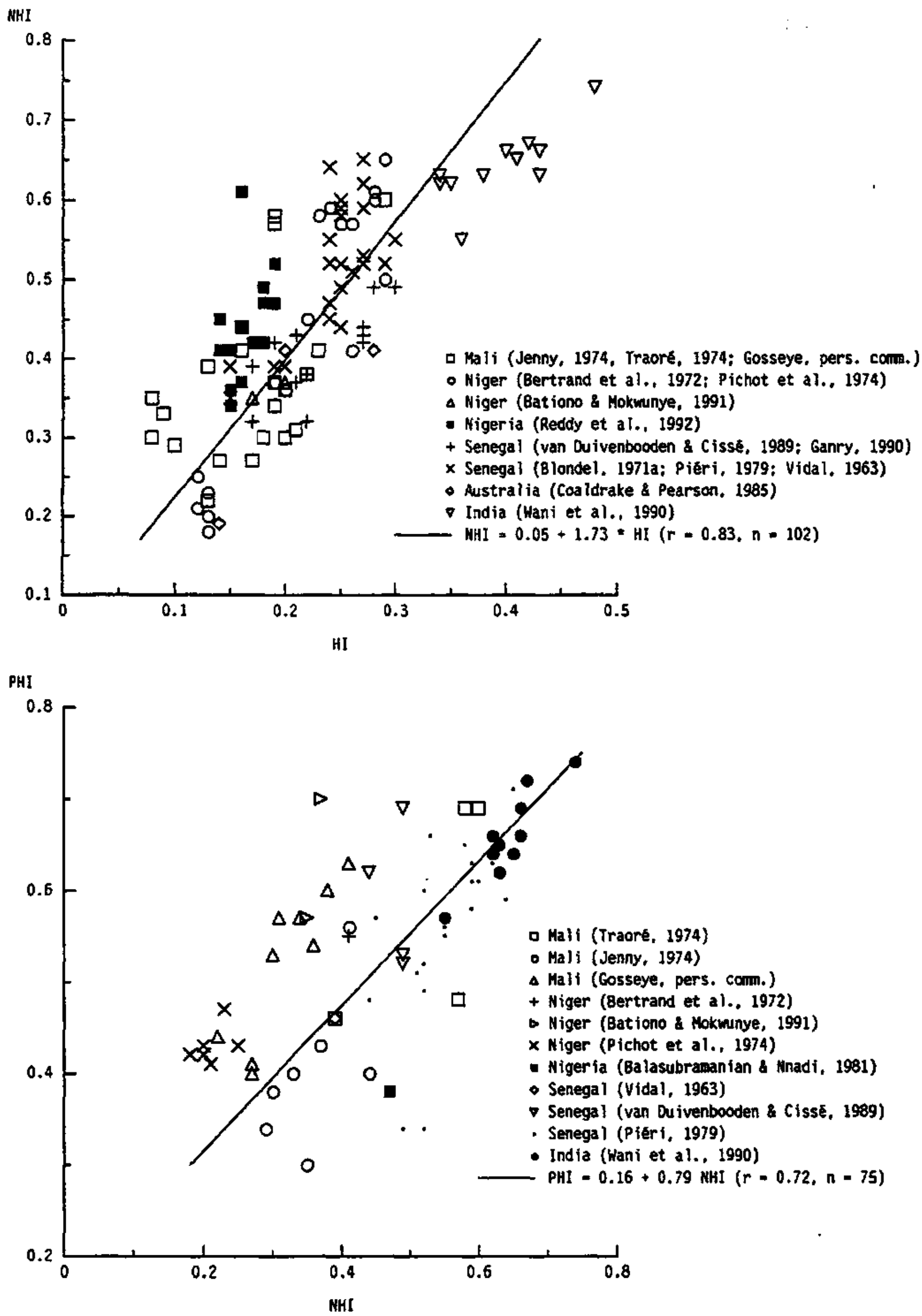


Figure 5.12. *Relation between a) harvest index and nitrogen harvest index and b) nitrogen harvest index and phosphorus harvest index of millet. Line represents average regression line.*

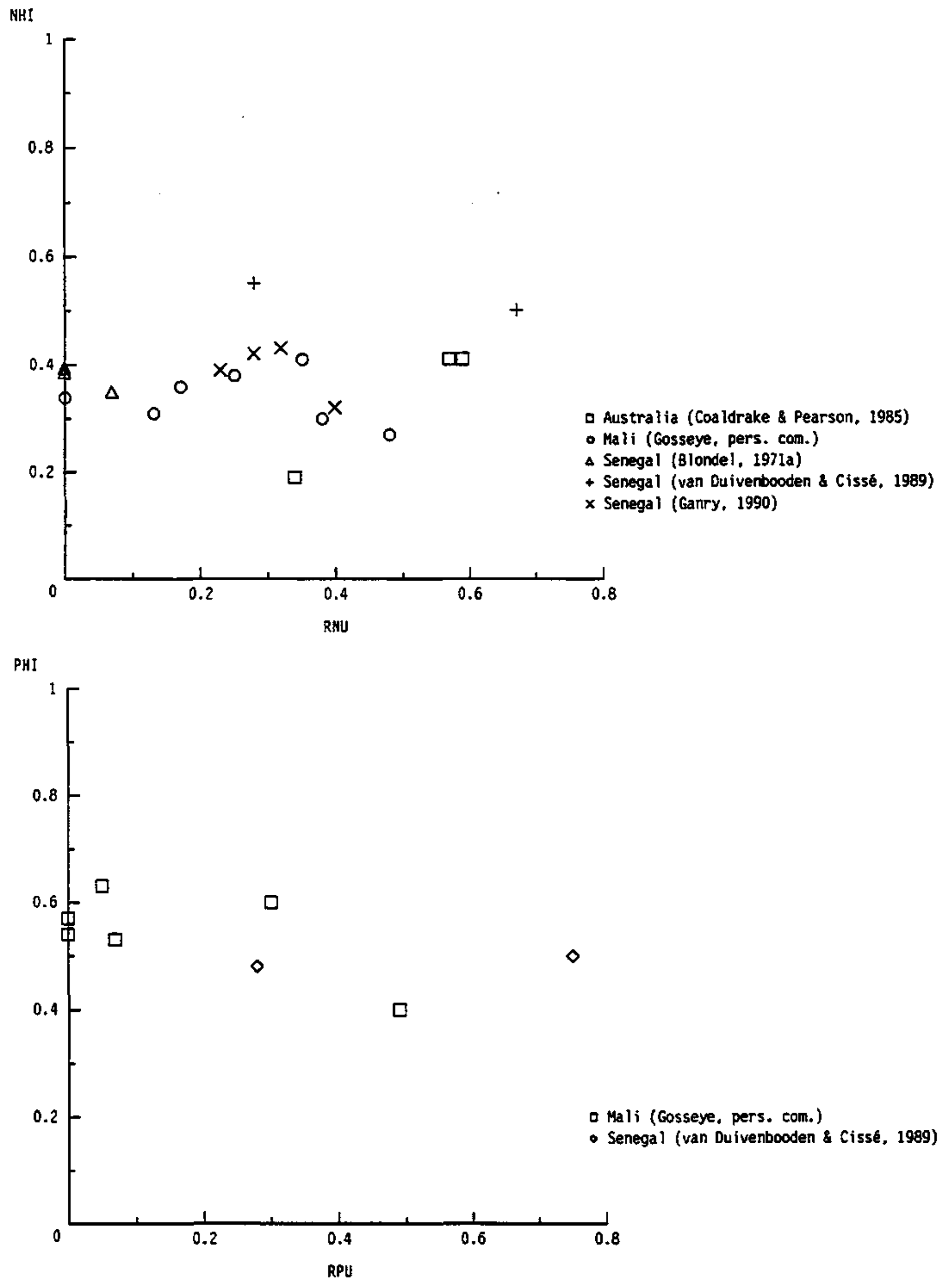


Figure 5.13. *Relation between relative post-anthesis nutrient uptake and nutrient harvest index in millet for a) nitrogen and b) phosphorus.*

6. SORGHUM

6.1 Dry matter distribution

Results on dry matter distribution are presented on the basis of simulation results for a flood-retreat sorghum (van Duivenbooden, 1991) as the relation grain to straw (Figure 6.1) and as the probability curve of reported harvest indices in world-wide experiments (Figure 6.2).

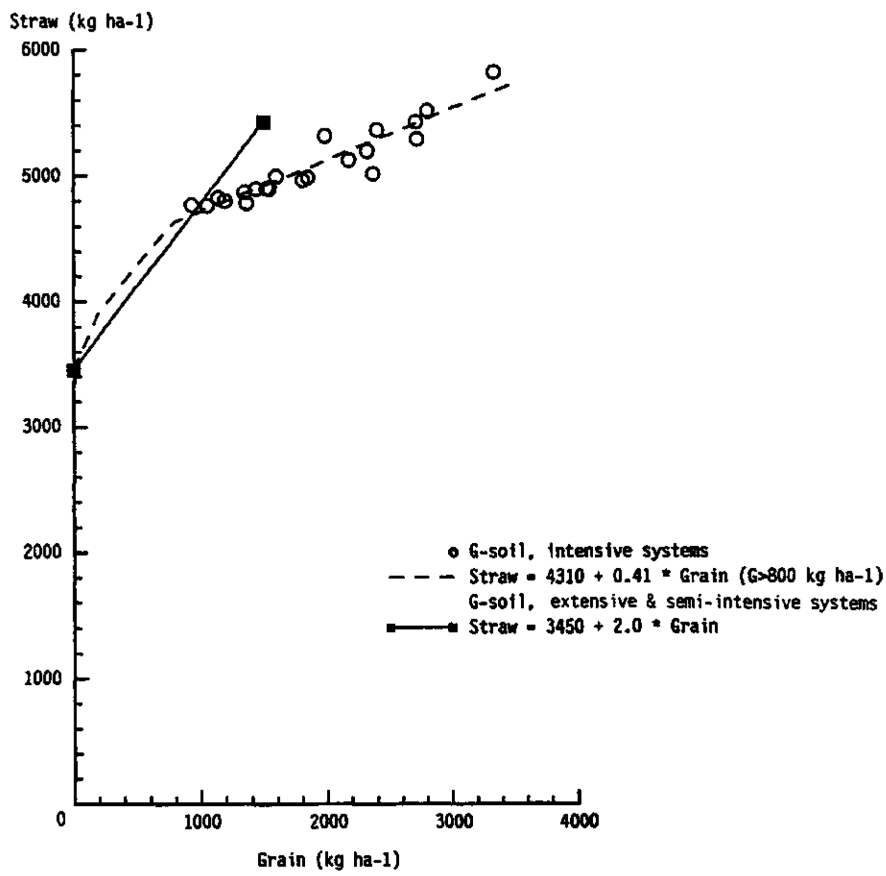


Figure 6.1. *Simulated relationship of flood-retreat sorghum straw and grain production for intensive production systems and estimated relationship for extensive and semi-intensive production systems.*

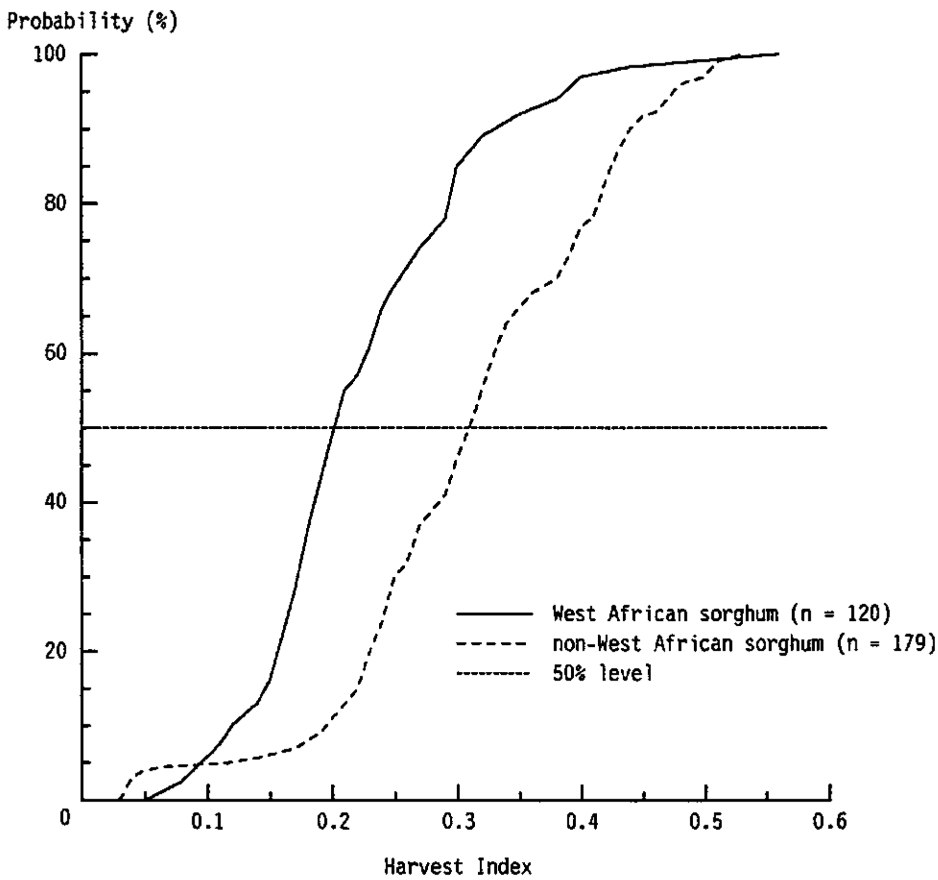


Figure 6.2. *Harvest index distribution of sorghum under different conditions.*

Sources West Africa: Arrivets, 1976; Blondel, 1971a,d; Deat et al., 1976; Djoulet & Fortier, 1989; Dupont de Dinechin, 1968; Gigou, 1981, 1984, 1986a,b; ICRISAT, 1989; Jacquinot, 1964; Jenny, 1974; Kassam & Stockinger, 1973; Ogunlela & Yusuf, 1988; Tourte et al., 1971; Ogunlela, 1983, 1988;

Elsewhere: van Arkel, 1978; Babu & Singh, 1984a,b; Blum et al., 1992; Gerakis & Tsangarakis, 1969; Locke & Hons, 1988; Maranville et al., 1980a; Meyers, 1978a,b; Muchow, 1989, 1990; Ofori, 1972; Rai, 1965a,b; Roy & Wright, 1973; 1974; Sadaphal & Singh, 1971; Seetharama et al., 1987;

Not included here, but for analysis of HI (Table 2.4) additionally used: Bennett et al., 1990; Muchow & Coates, 1986; Perry & Olson, 1975; Turkhede & Prasad, 1980.

Further available, but not included due to time restrictions: Goldsworthy, 1970; Powell & Hons, 1992.

6.2 Concentration of major elements

Table 6.1. *Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total above-ground biomass of sorghum at maturity; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
Burkina	S29	4.3	4.9	22.9	23.8	6.2	10.5	Arrivets, 1976
	S29	3.1	5.2	15.0	17.6	5.3	7.8	Arrivets, 1976
		2.3	4.7	15.8	19.7	4.8	9.3	Dupont de Dinechin, 1968
Cameroun	IRAT55			11.0	17.1			Gigou, 1984
			4.1	13.3				Gigou, 1980
Gambia		2.7						Russo, 1986
Mali		5.6	8.2	18.8	20.2	9.0	10.2	Jenny, 1974
Nigeria						5.0		Kassam & Stockinger, 1974
			5.8					Balasubramanian & Nnadi, 1981
		3.5						Okaiyeto, 1984
Senegal			5.2		18.0		8.4	Blondel, 1971d
				16.4	17.6			Vidal *ea*, 1962
	Hazera610					2.4	9.8	Tourte *ea*, 1964
	Hazera610				22.0			Tourte *ea*, 1971
		3.8			21.4		8.5	Jacquinot, 1964
General			6.2	16.3				RFMC, 1980
General			6.4	17.4				Euroconsult, 1989
General				19.2				Sinclair & de Wit, 1975
Australia				12.3	24.4			Muchow, 1990
				12.0	18.8			Muchow, 1988
		5.9	8.8	17.4	18.8			Myers, 1978b
India	8 varieties			10.9	31.4			Subramanian *ea*, 1990
	CSH-I			13.3	18.9			Roy & Wright,1973
	1967	9.3	11.2	16.1	21.8			Singh &
	1968	8.8	11.8	14.6	19.4			Bains, 1973
Sudan	Um Benein	4.1	7.9	11.7	20.2			Rai, 1965a
	Wad Aker	2.7	9.2	15.0	16.0			Rai, 1965a
	Wad Aker			12.8	22.4	7.9	13.8	Rai, 1965b
USA		8.3	11.5	11.4	15.5			Perry & Olson,
		7.0	11.5	10.7	15.6			1975
		7.8	11.2	11.5	18.3			Perry & Olson,
		7.5	12.6	11.5	18.7			1975
		6.8	11.7	16.2	19.9			Maranville *ea*, 1980a
	blades and stalks	2.3	6.0					Powell ea, 1991
				10	20			Bennett ea, 1990

.../...

Table 6.1. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Phosphorus								
Burkina	S29	0.3	1.2	2.3	2.7	0.7	1.5	Arrivets, 1976
	S29	0.5	1.0	1.3	1.8	0.6	1.4	Arrivets, 1976
		0.2	0.4	2.4	3.4	0.5	0.8	Dupont de Dinechin, 1968
Cameroun	N-fert.exp.			2.8	3.4			Gigou, 1984
			0.9		3.3			Gigou, 1980
Mali		0.2	0.3	1.6	2.3	0.2	0.7	Jenny, 1974
Nigeria			1.0					Balasubramanian & Nnadi, 1981
Senegal	Hazera610					0.8	1.4	Tourte *ea*, 1964
	Hazera610			2.2				Tourte *ea*, 1971
	SH60	0.2		2.3		0.8		Jacquinot, 1964
		0.5						Richard *ea*, 1989
General			1.0		3.8			RFMC, 1980
Sudan				2.0	3.1	0.9	1.5	Rai, 1965b
India		0.6	0.9	1.4	2.4			Turkhede & Prasad, 1980
Australia		0.4	1.2	1.8	3.7			Myers, 1978b
		0.4		1.9	2.2			Myers, 1978b
USA		1.4	2.1	3.1	3.8			Maranville *ea*, 1980a
	blades and stalks	0.8	1.4					Powell *ea*, 1991
				2	4			Bennett *ea*, 1990
Potassium								
Burkina	S29	5.7	16.6	2.8	3.0	8.8	11.6	Arrivets, 1976
	S29	8.9	9.1	4.4	4.5	8.2	10.5	Arrivets, 1976
						4.8	8.3	Dupont de Dinechin, 1968
Cameroun	N-fert.exp.			3.9	4.6			Gigou, 1984
Mali		12.4	18.0	2.7	2.9	10.2	14.4	Jenny, 1974
Nigeria		15.1						Balasubramanian & Nnadi, 1981
Senegal	Hazera610			4.1				Tourte *ea*, 1971
	SH60	3.1			4.1	3.4		Jacquinot, 1964
USA	blades and stalks	13.2	20.7					Powell *ea*, 1991
				3	5			Bennett *ea*, 1990
Calcium								
Burkina	S29	1.3	2.2	0.2	0.2	1.1	1.8	Arrivets, 1976
	S29	0.4	1.2	0.6	0.9	0.4	1.4	Arrivets, 1976
		1.1	1.6	0.1	0.1	0.9	1.4	Dupont de Dinechin, 1968
Mali		1.7	2.0	0.3	0.4	1.4	1.7	Jenny, 1974
Nigeria		2.1	-					Balasubramanian & Nnadi, 1981
Senegal	Hazera610					2.0	4.7	Tourte *ea*, 1964
	Hazera610			1.0				Tourte *ea*, 1971
	SH60		3.2		0.9		2.5	Jacquinot, 1964
			2.7					Richard *ea*, 1989

.../...

Table 6.1. Continued.

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Calcium								
General		4.8		0.3				RFMC, 1980
USA				0.3	0.5			Bennett *ea*, 1990
Magnesium								
Burkina	S29	1.2	1.5	1.2	1.3	1.2	1.5	Arrivets, 1976
	S29	0.8	1.8	1.4	2.0	0.9	2.3	Arrivets, 1976
		1.0	1.7	0.9	1.6	1.1	1.7	Dupont de Dinechin, 1968
Mali		1.6	2.1	1.1	1.3	1.5	1.9	Jenny, 1974
Nigeria		1.3						Balasubramanian & Nnadi, 1980
Senegal	Hazera610					0.5	1.2	Tourte *ea*, 1964
	SH60		3.6		2.8		3.4	Jacquinot, 1964
USA				1	2			Bennett *ea*, 1990
Sulphur								
Burkina		0.8	2.7	1.1	1.4	0.9	2.4	Dupont de Dinechin, 1968
Mali		0.4	0.9	0.8	1.2	0.6	0.9	Jenny, 1974
Nigeria		1.0						Balasubramanian & Nnadi, 1981
Senegal	Hazera610			0.7	2.5			Tourte *ea*, 1964
	SH60		0.9	0.2		0.8		Jacquinot, 1964

With respect to the data in Table 6.1, the following remarks may be made. The minimum P-concentration in grains is 0.2 g kg^{-1}, but for crop growth as food-retreat sorghum in the period January-May (van Duivenbooden *et al.*, 1991, p. 64), this would lead to a relatively low P/N ratio, hence in that case, the minimum value is set at 0.3 g kg^{-1}.

The lowest reported K concentration in straw equals 3.3 g kg^{-1} (Jacquinot, 1964), but considering the ratio K-content/total aboveground dry matter, and the other reported concentrations, this value is considered a measurement error.

6.3 Three quandrant figures

6.3.1 Nitrogen

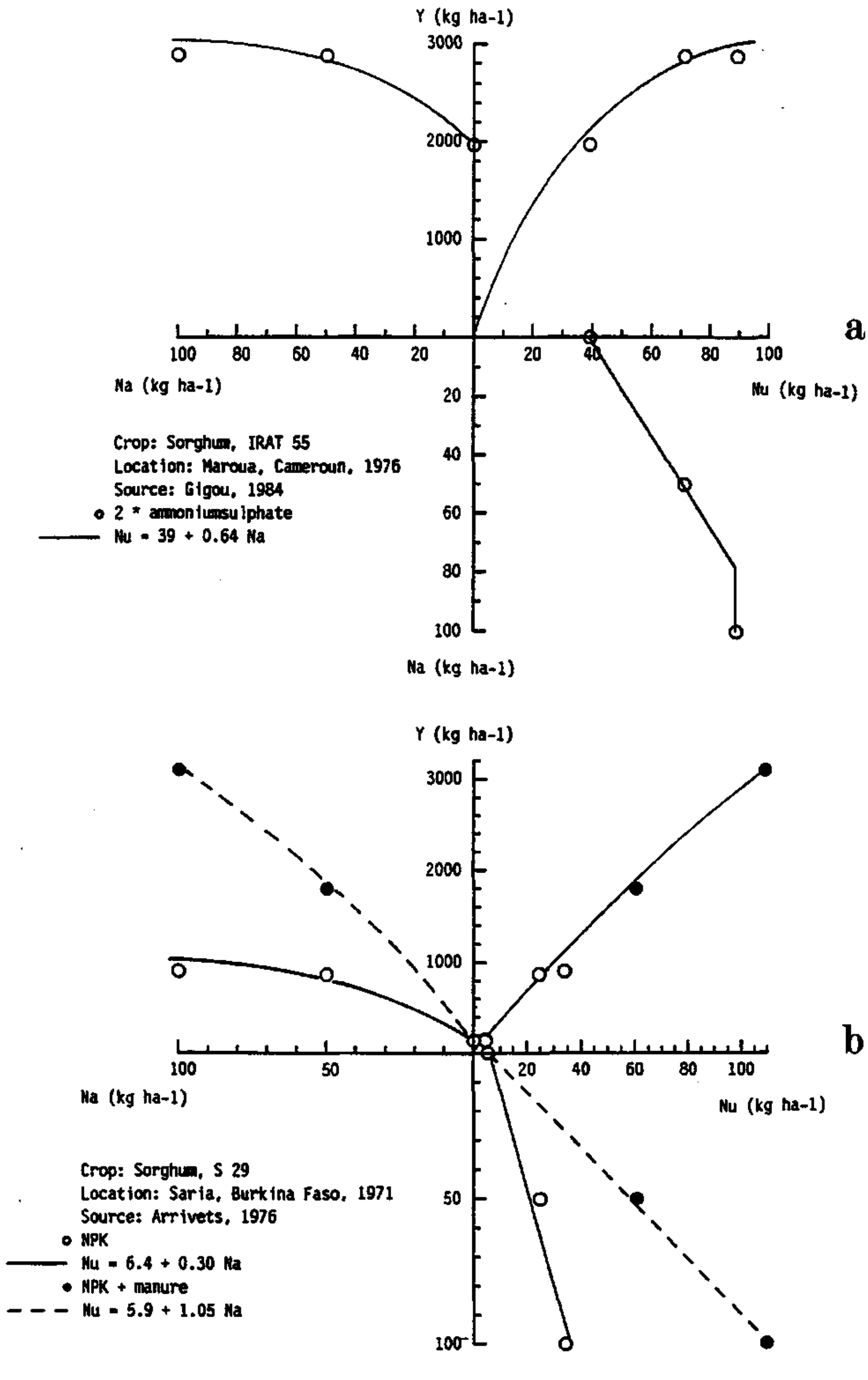


Figure 6.3. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield.*

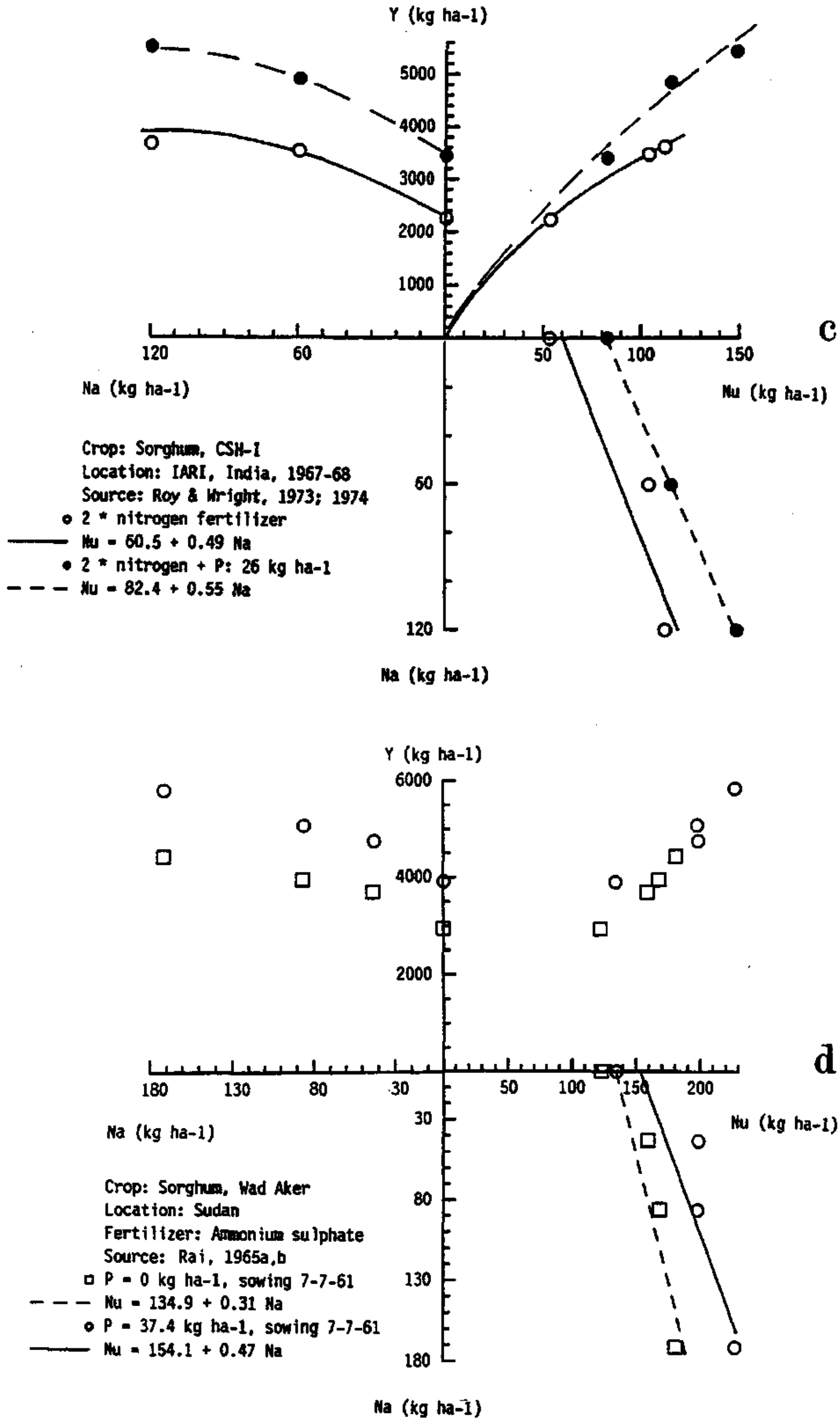


Figure 6.3. Continued.

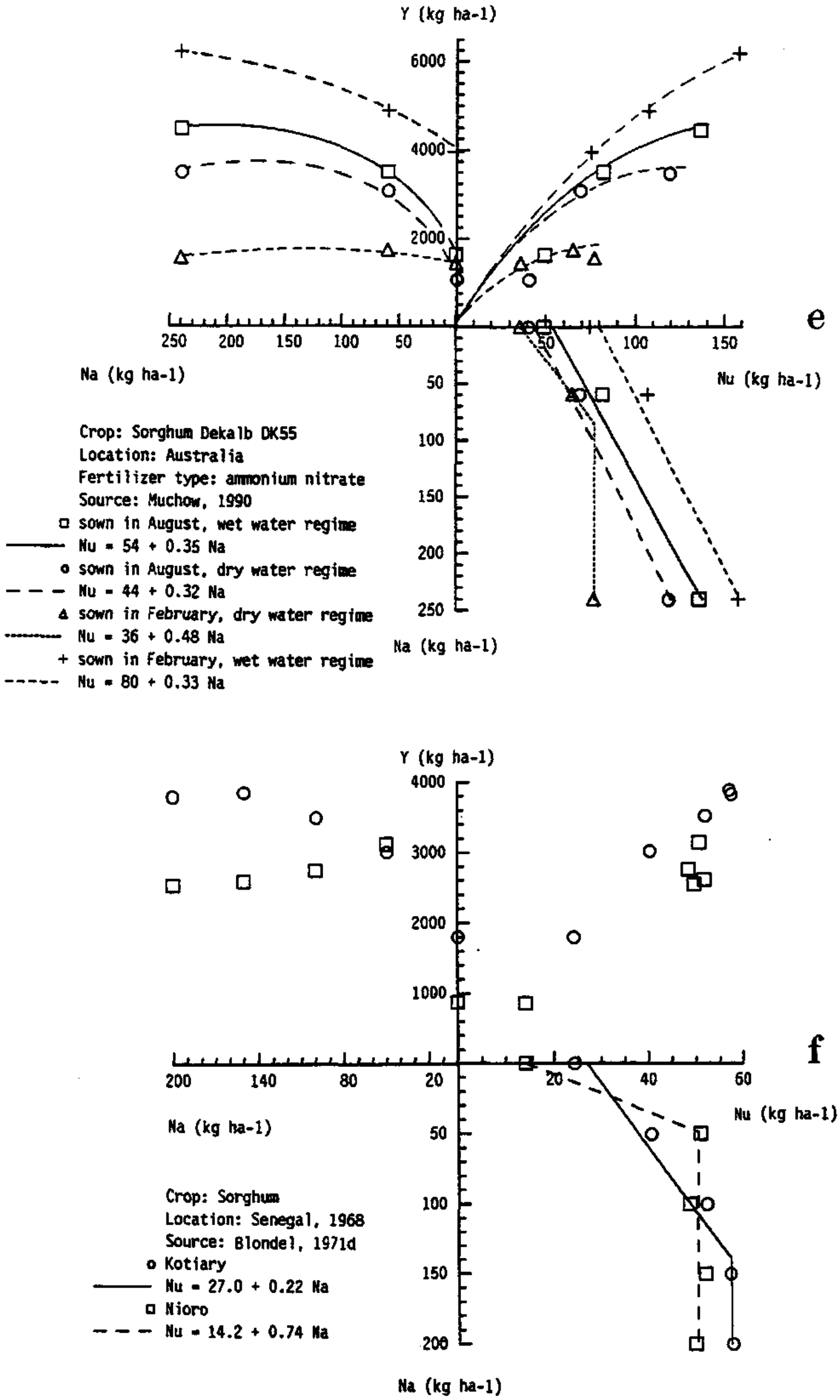


Figure 6.3. Continued.

6.3.2 Phosphorus

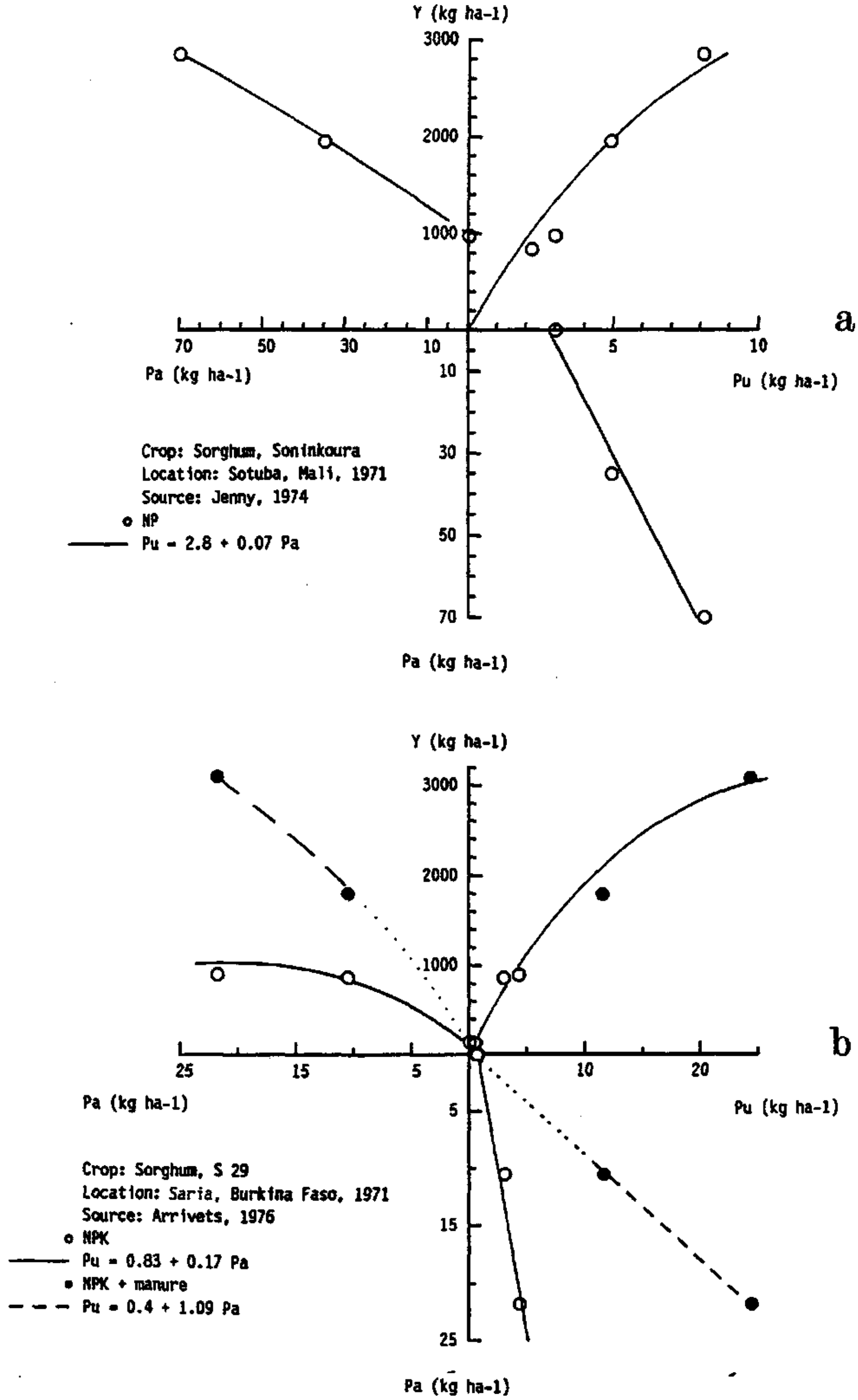
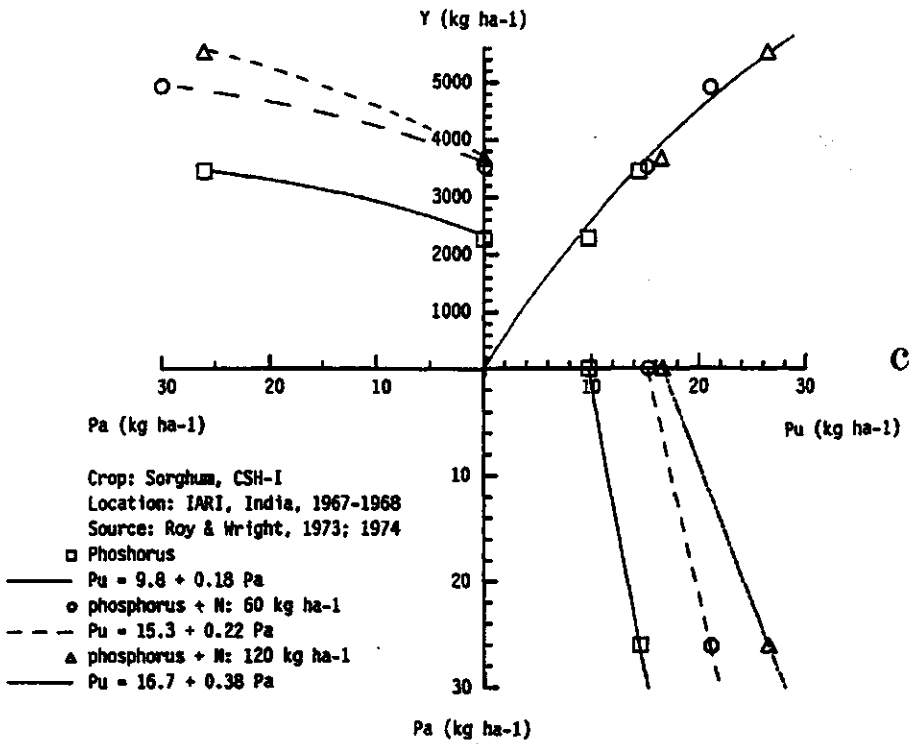


Figure 6.4. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*



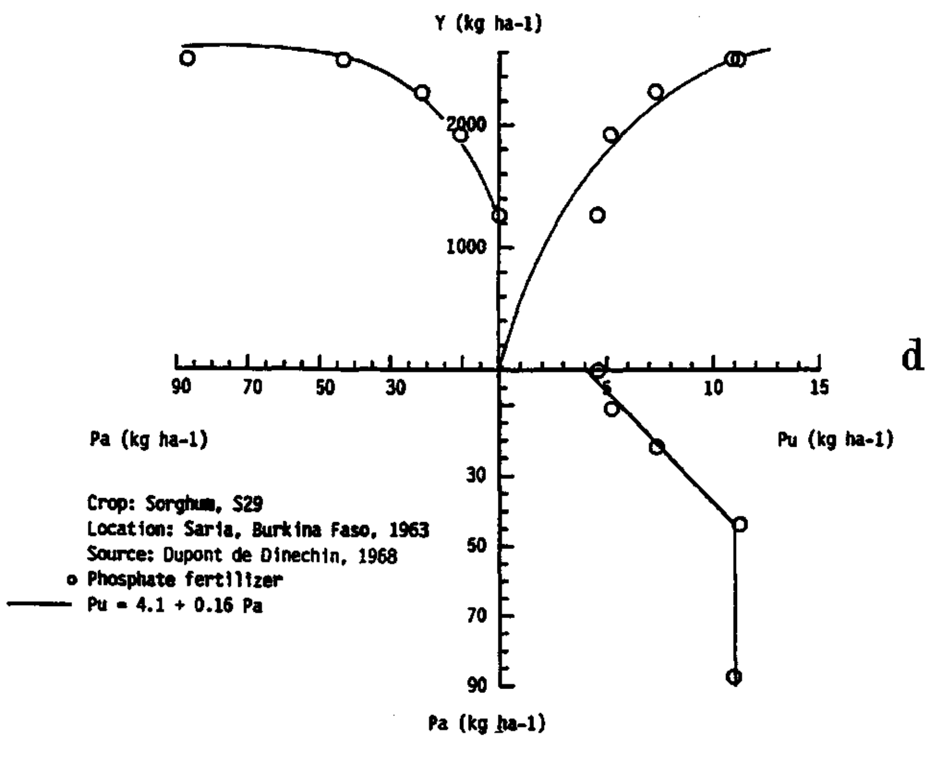


Figure 6.4. Continued.

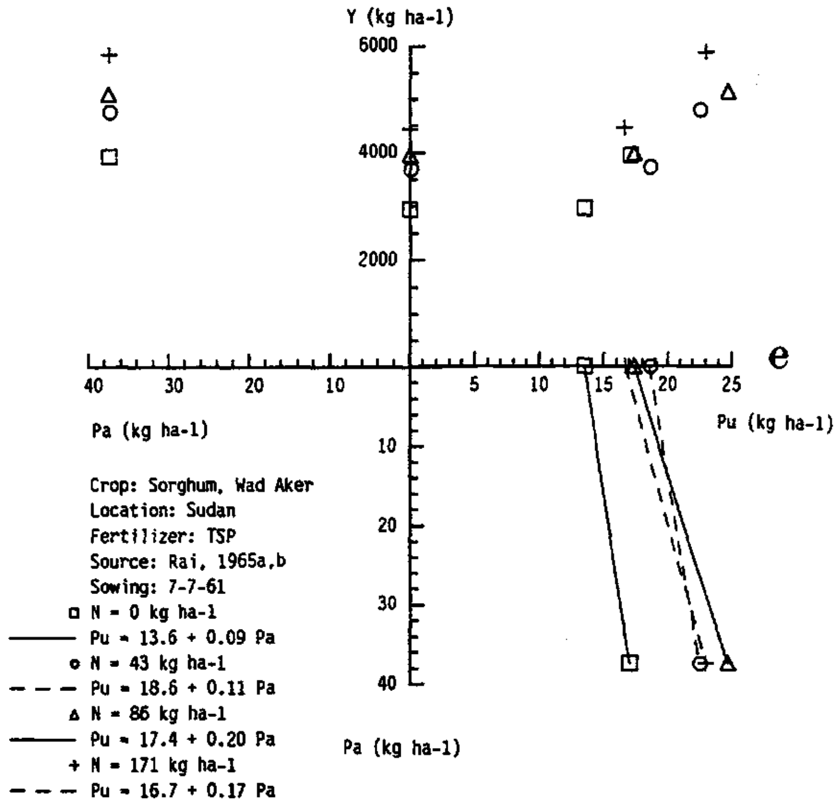


Figure 6.4. Continued.

6.4 Nutrient content as related to yield

In contrast to millet, no differences in initial slopes between locations in sorghum exist (Figures 6.5, 6.6 and 6.7).

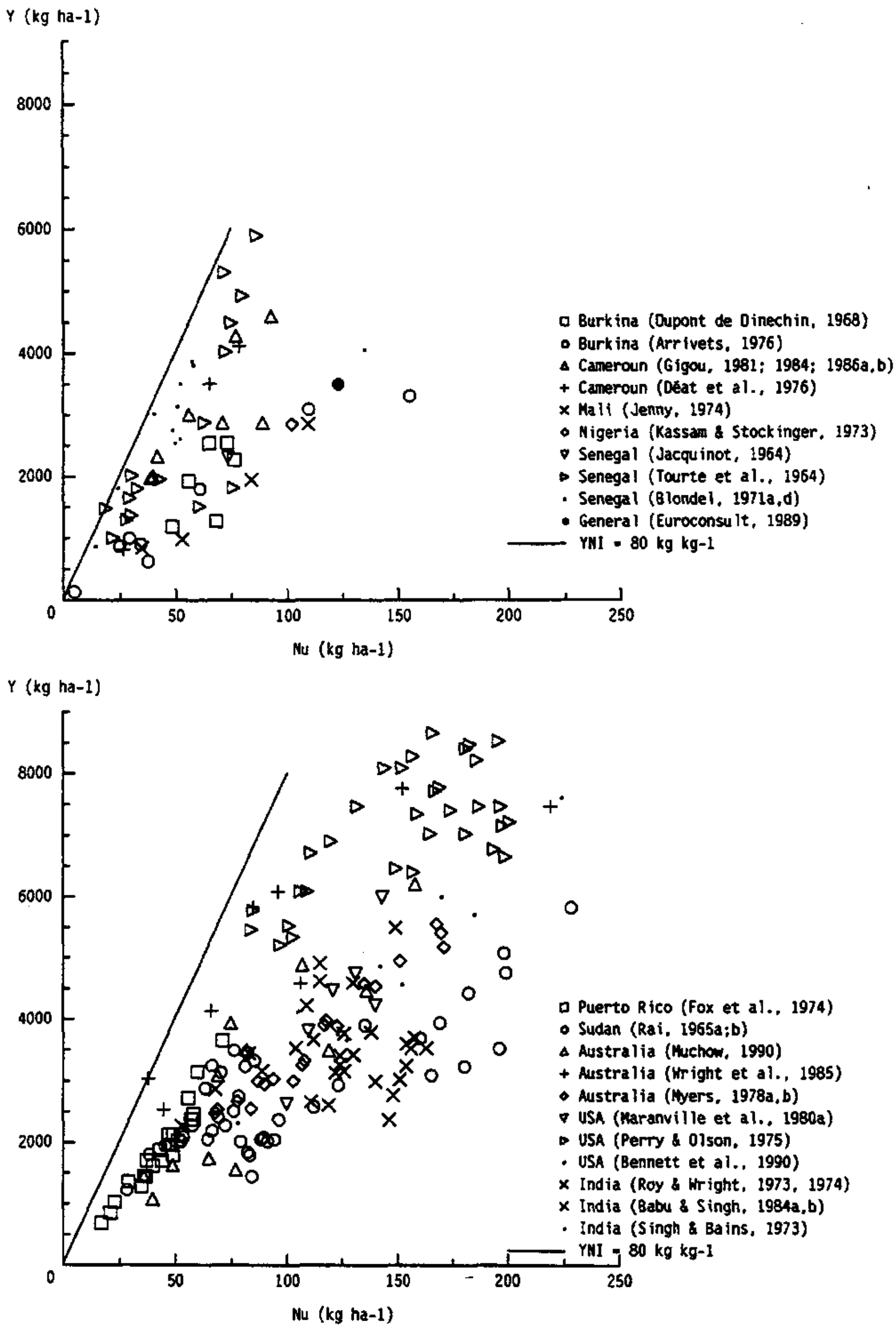


Figure 6.5. *Relation between total nitrogen content (N_u) and yield (Y), a) in West Africa and b) elsewhere; YNI = initial slope.*

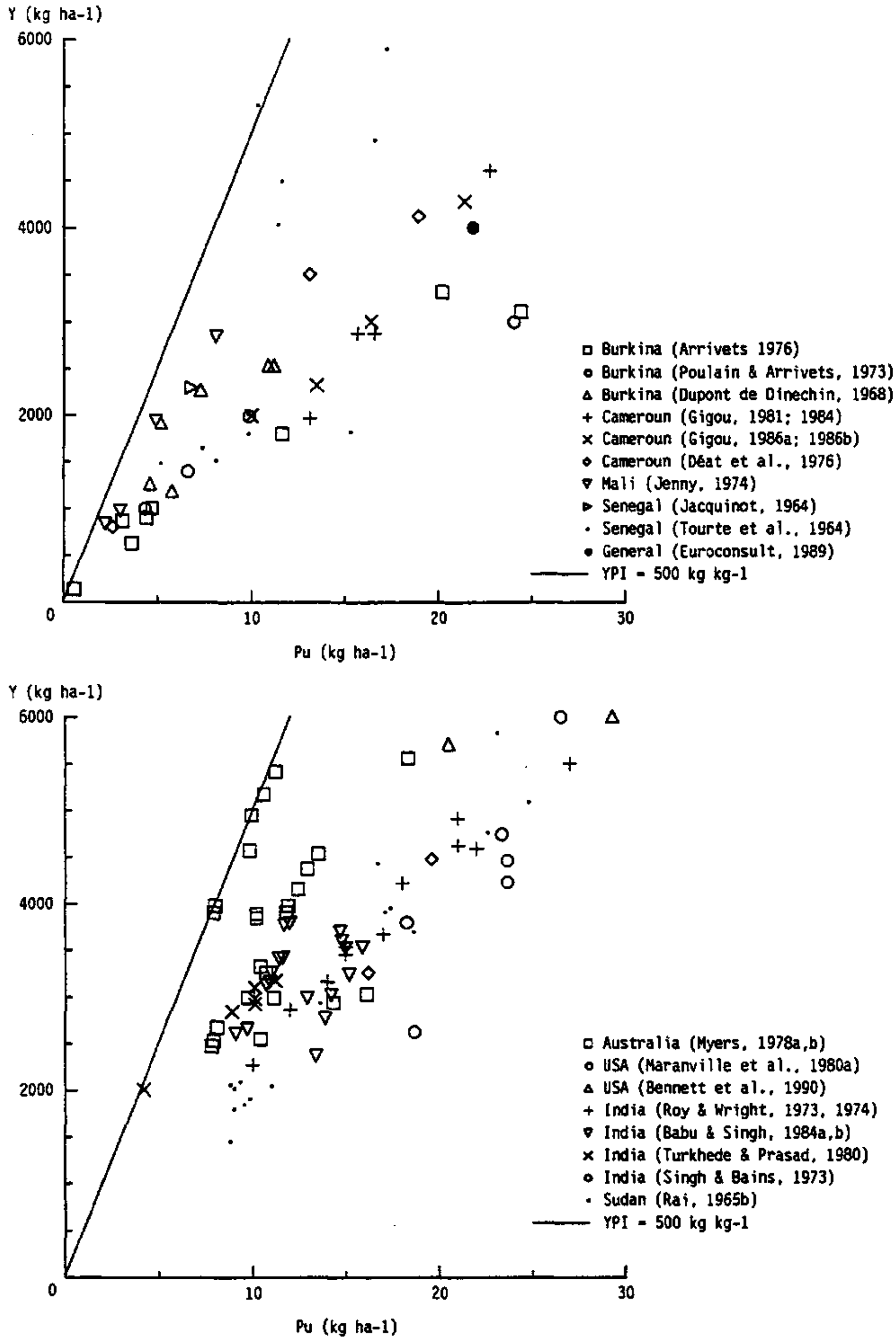


Figure 6.6. *Relation between total phosphorus content (P_u) and yield (Y), a) in West Africa and b) elsewhere; YPI = initial slope.*

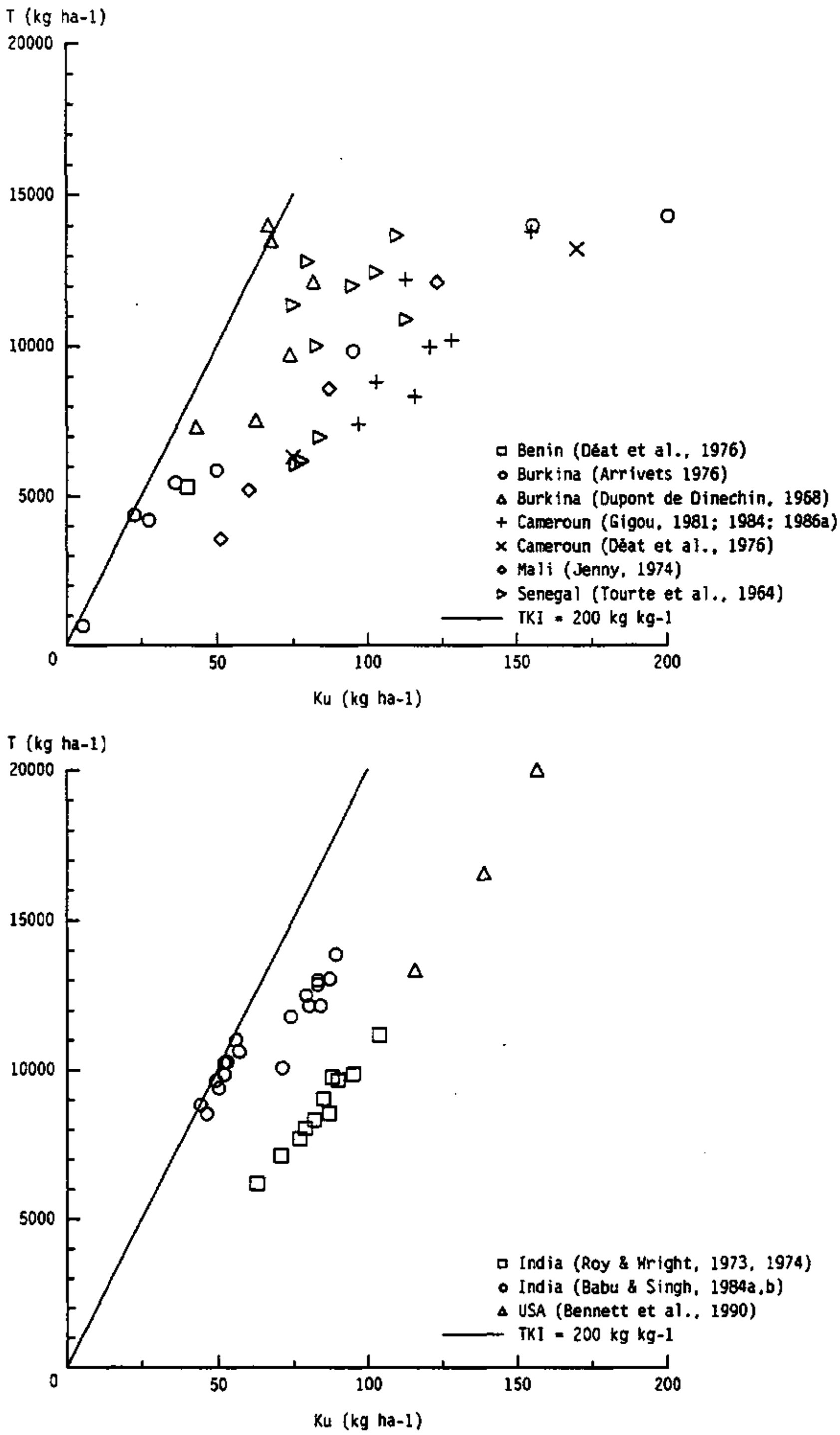


Figure 6.7. *Relation between total potassium content (K_u) and total aboveground dry matter (T), a) in West Africa and b) elsewhere; TKI = initial slope.*

The value of K-content at maturity reported by Jacquinot (1964) is in relation to other values relative low, hence not included in Figure 6.7. This very low K-uptake is compensated by a relative high Ca and Mg uptake (Figure 6.8).

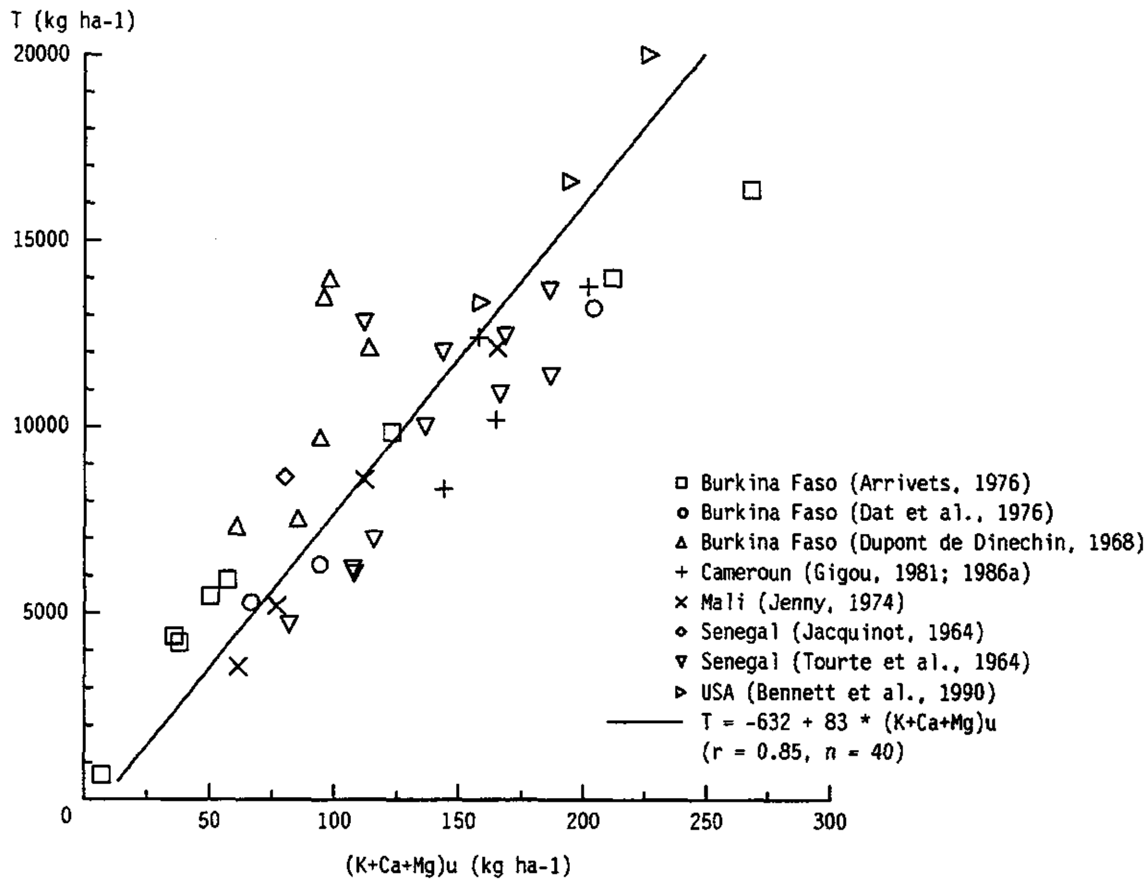


Figure 6.8. *Relation between the combined content of potassium, calcium and magnesium $(K+Ca+Mg)_u$ and total above-ground dry matter (T) in sorghum. Line represents average regression line.*

6.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 6.9; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

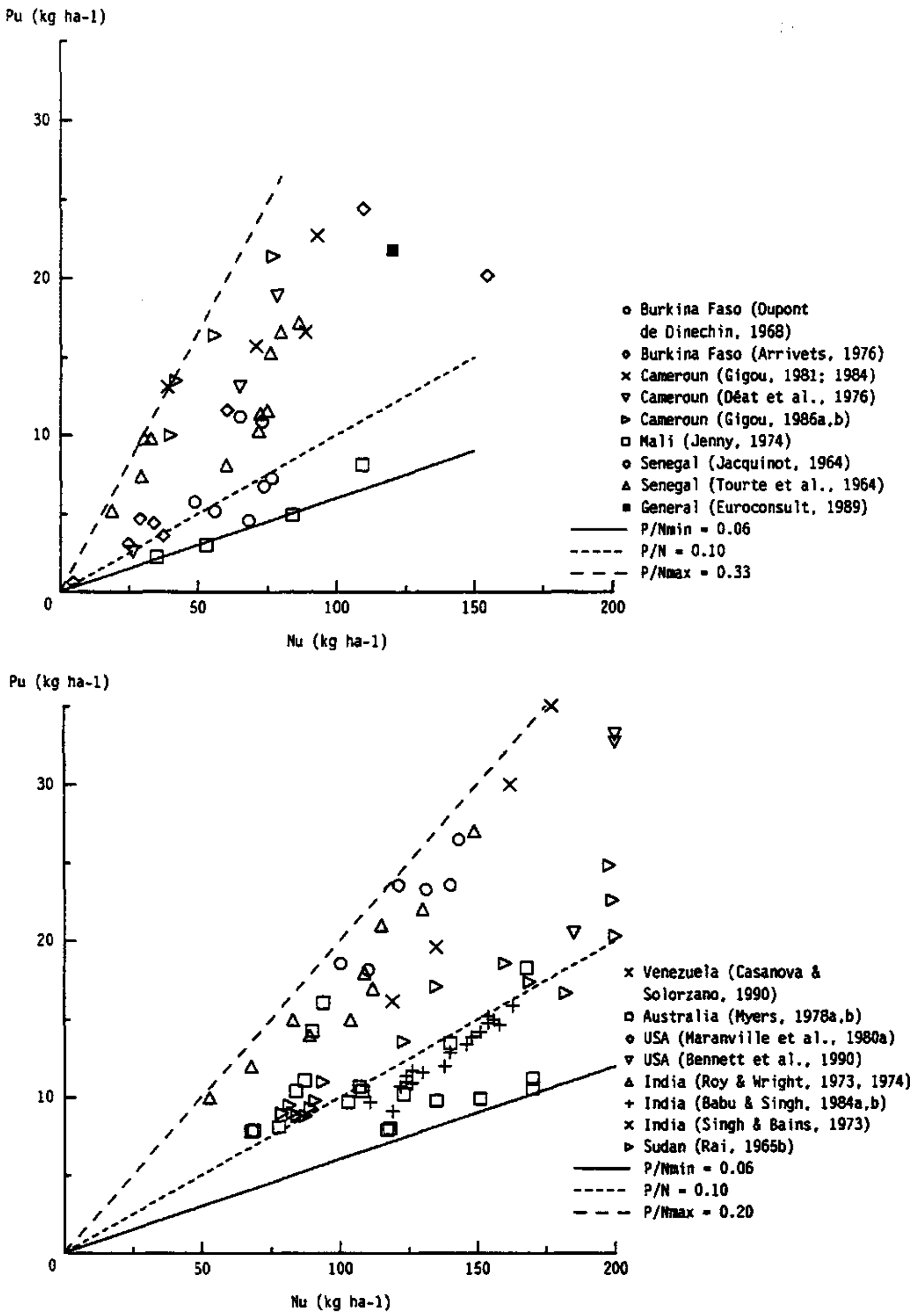


Figure 6.9. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of sorghum, a) in West Africa and b) elsewhere.*

6.6 Relations among relative post-anthesis nutrient uptake values of N, P and K

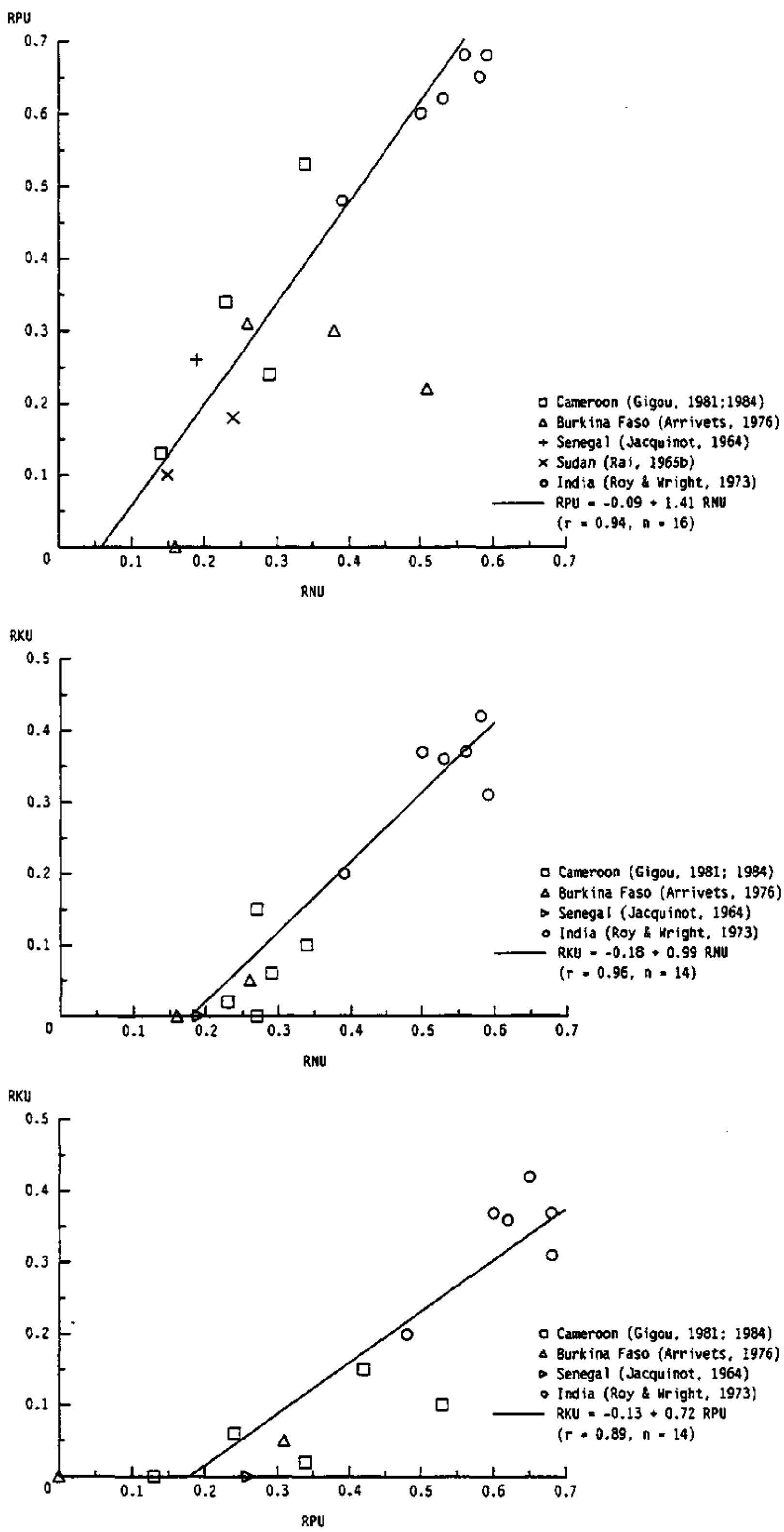


Figure 6.10. *Relationship between relative post-anthesis nutrient uptake in sorghum of a) nitrogen and phosphorus, b) nitrogen and potassium and c) phosphorus and potassium. Line represents average regression line.*

6.7 Nutrient harvest indices

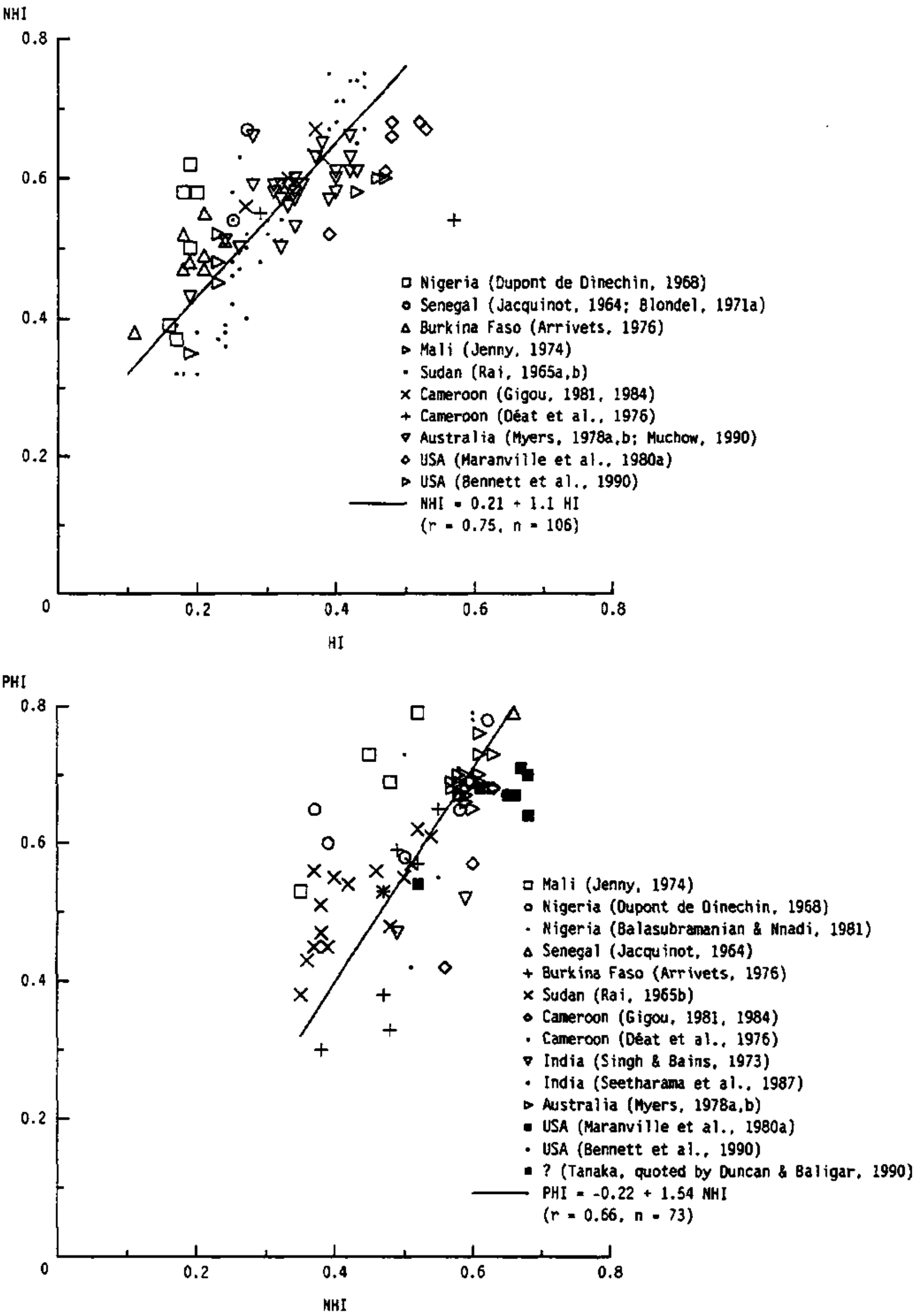


Figure 6.11. *Relation between a) harvest index and nitrogen harvest index and b) nitrogen harvest index and phosphorus harvest index of sorghum. Line represents average regression line.*

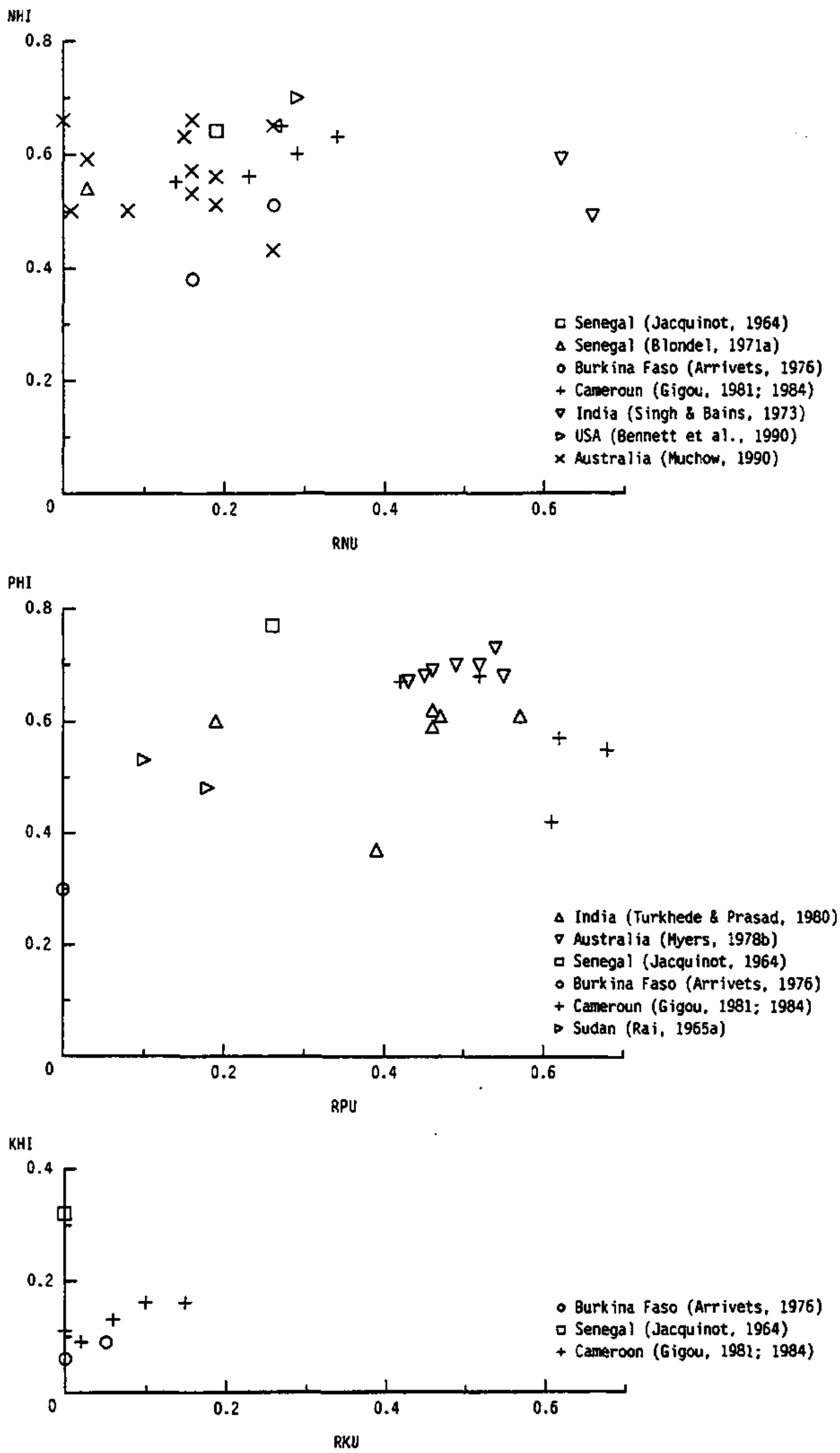


Figure 6.12. *Relation between relative post-anthesis nutrient uptake and nutrient harvest index in sorghum for a) nitrogen, b) phosphorus and c) potassium.*

Additional data on relative nitrogen uptake (RNU), harvest index (HI) and nitrogen harvest (NHI) in sorghum are reported by Youngquist & Maranville (1992), but could not anymore be included in the analysis performed.

7. MAIZE

Although maize has not been distinguished as a separate crop for the Fifth Region of Mali, but as part of vegetables (van Duivenbooden *et al.*, 1991), maize has been included in this study for the purpose of future elaboration to other regions.

7.1 Dry matter distribution

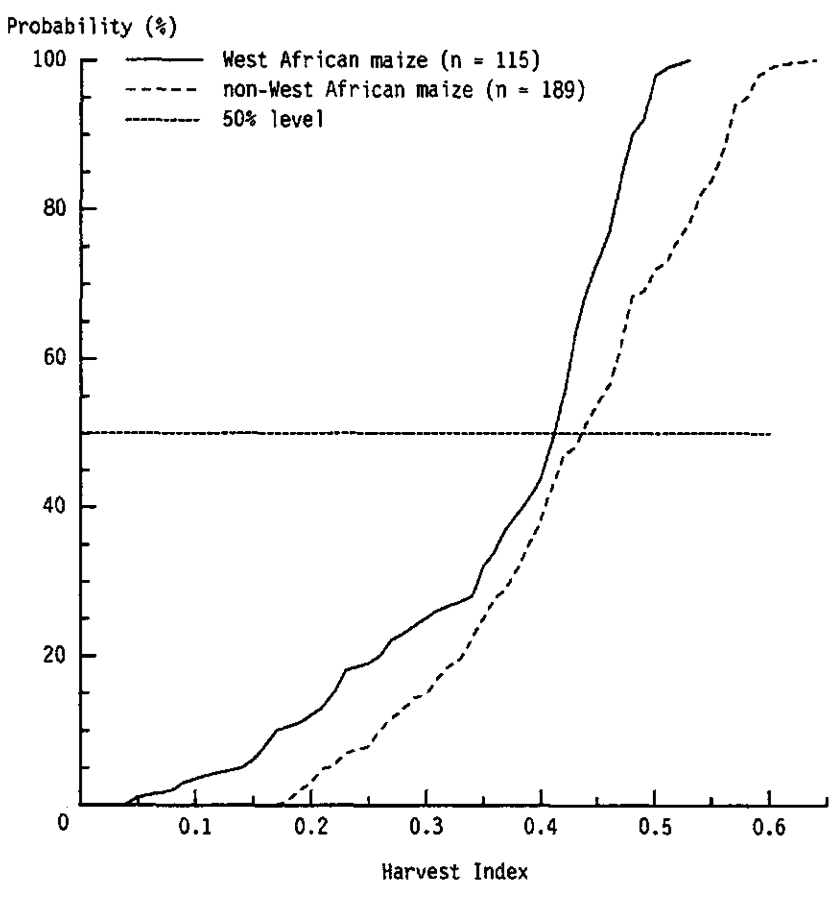


Figure 7.1. *Harvest index distribution of maize under different conditions.*

Sources West Africa: Arora & Juo, 1982; Balasubramanian & Singh, 1982; Blondel, 1971a; Bromfield, 1969; Chopart, 1990; Dupont de Dinechin, 1968; Ganry, 1990; Jenny, 1974; Jones, 1976; Kang & Yunusa, 1977; Kang & Osiname, 1979; Sené, 1989; Traoré, 1974; Vaksmann & Traoré, 1989;

Elsewhere: Anderson et al., 1984b; 1985; Beauchamp et al., 1976; Dass & Singh, 1979; di Fonzo et al., 1982; Grove et al., 1980; Jordan et al., 1950; Karlen et al., 1988; Lubet & Juste, 1985; Mackay & Barber, 1986; Maddux et al., 1991; Mehla & Singh, 1980; Moll et al., 1987; Ofori & Stern, 1986; Rai, 1965a,b; Sayre, 1948; Sisworo et al., 1990; Sparks et al., 1980; Thakur et al., 1990; Thiraporn et al., 1983; Thom & Watkin, 1978; Totawat & Saeed, 1990.

Not included here, but for analysis of HI (Table 2.4) additionally used: Ahlawat et al., 1981; Atanasiu et al., 1978a; Loué, 1963; Muchow, 1989; Piéri, 1985.

7.2 Concentration of major elements

Table 7.1. *Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total above-ground biomass of maize at maturity; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
Gambia		5.0						Russo, 1986
Mali		6.9	11.4	17.5	21.2			Jenny, 1974
		5.6	9.0	8.8	19.0			Jenny, 1974
		4.8	7.6	13.4	17.1			Traoré, 1974
Nigeria	(south)			12.1	15.1			Kang *ea*, 1977
		7.0						Balasubramanian & Nnadi, 1981
				11.4	14.7			Balasubramanian & Singh, 1982
				11.9				Dupont de Dinechin, 1968
				23.8	26.7			Singh & Balasu-bramanian, 1983
						12.6		Bromfield, 1969
Senegal		5.9	7.3	16.9	18.0			Blondel, 1971a
			6.4					Richard *ea*, 1989
Australia				10.7	15.8			Muchow, 1988
				15.1	17.8			Thiagalingam *ea*, 1991
				11	16	8	13	Ofori & Stern, '87
France		7.4	12.4	16.2	18.8			Loué, 1963
General					17.6			Euroconsult, 1989
					16.0			Sinclair & de Wit, 1975
India		5.7	6.6	15.2	17.1			Ahlawat ea, 1981
				16.4	18.7			Verma *ea*, 1972
						10.4	11.1	Thakur *ea*, 1990
						11.9	17.2	Totawat & Saeed, 1990
Indonesia		6.3	6.8	14.5	15.3	10.3	10.5	Sisworo *ea*, 1990
Netherlands						13.4	15.2	Schröder & Dilz, 1987
Sudan				14.4	15.8			Rai, 1965a
				13.0	19.6	6.2	12.3	Rai, 1965b
Thailand				12.3	18.2			Thiraporn *ea*, 1983
USA		4.4	6.8	12.4	15.5			Moll *ea*, 1987
				12.2	18.1			Deckard *ea*, 1973
		5.9	6.7	13.1	15.0			Perry & Olson,
		5.3	7.4	12.8	15.3			1975
		4.5	7.2	11.1	14.6			Perry & Olson,
		4.6	6.2	11.0	14.1			1975
				13.2	17.5			Anderson *ea*, 1984b

.../...

Table 7.1. Continued.

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
USA	irrigated					9	10	Rhoads & Stanley, 1981
		5.7	11.1	13.7	18.1	10.0	13.7	Beauchamp *ea*, 1976
	134 kg N ha^{-1}	6.5	11.7	23.0	27.6			Tsai *ea*, 1991
	268 kg N ha^{-1}	9.8	16.8	24.0	34.0			Tsai *ea*, 1991
Phosphorus								
Ivory Coast	(leaves)	0.2	0.3					Pichot *ea*, 1978
Mali		0.4	1.0	1.8	2.7	0.8	1.8	Jenny, 1974
		0.3	0.6	1.7	2.6	0.9	1.6	Jenny, 1974
		0.2	0.5	1.6	2.2			Traoré, 1974
Nigeria				1.7	2.3			Kang *ea*, 1977
		0.5	1.0	2.0	4.0	1.6	2.4	Kang & Yunusa,
		0.3	1.0	1.7	3.9	0.9	2.4	1977
		0.8	1.2	2.9	4.3	1.6	2.5	Kang & Osiname, 1979
		0.3	0.4	2.5	2.9	1.4	1.7	Atanasiu *ea*,
		0.3	0.4	2.5	2.8	1.5	1.8	1978
						1.1		Bromfield, 1969
			1.4					Balasubramanian & Nnadi, 1981
				2.4				Dupont de Dinechin, 1968
				3.3	4.4			Singh & Balasubramanian, 1983
Senegal		0.7						Richard *ea*, 1989
Australia				3.0	5.5			Thiagalingam *ea*, 1991
France		0.4	2.2	2.0	3.7			Loué, 1963
						1.9		Lubet & Juste, 1985
India						2.0	2.1	Mehla & Singh, 1980
						1.8	2.0	Thakur *ea*, 1990
						1.1	1.4	Totawat & Saeed, 1990
Netherlands						1.8	3.1	Schröder & Dilz, 1987
Sudan				2.1	3.1	0.8	1.2	Rai, 1965b
Thailand				2.7	3.8	1.8	2.7	Thiraporn *ea*, 1983
USA	irrigated					2.0	2.3	Rhoads & Stanley, 1981
							2.4	Sayre, 1948

.../...

Table 7.1. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Potassium								
Mali		7.9	10.2	3.1	3.7	7.4	9.3	Jenny, 1974
		11.8	16.4	3.2	4.0	9.4	11.0	Jenny, 1974
		10.0	12.7	3.1	3.9			Traoré, 1974
Nigeria		8.5		4.0				Jones, 1976
Nigeria	(south)			3.4	5.2			Kang *ea*, 1977
		14.3						Balasubramanian & Nnadi, 1981
				3.2				Dupont de Dinechin, 1968
				4.7	5.7			Singh & Balasubramanian, 1983
						7.8		Bromfield, 1969
Australia				4.0	6.7			Thiagalingam *ea*, 1991
France		2.7	17.5	2.7	4.1			Loué, 1963
						8.4		Lubet & Juste, 1985
India						6.1	6.3	Mehla & Singh, 1980
						8.0	8.6	Thakur *ea*, 1990
						16.0	18.5	Totawat & Saeed, 1990
Netherlands						11.6	17.3	Schröder & Dilz,
						11.6	19.0	1987
USA		13.2	24.6	2.9	4.3	12.6	23.7	Sparks *ea*, 1980
		8.9	9.4	2.4	2.5	5.9	6.0	Sparks *ea*, 1980
	irrigated					12	13	Rhoads & Stanley, 1981
						7.9		Sayre, 1948
Calcium								
Mali		3.3	4.0	0.5	0.6			Jenny, 1974
		2.2	3.2	0.5	0.6			Jenny, 1974
		2.3	3.8	0.5	0.6			Traoré, 1974
Nigeria		2.6		0.1				Jones, 1976
Nigeria	(south)			0.6	0.7			Kang *ea*, 1977
			3.6					Balasubramanian & Nnadi, 1981
				0.5				Dupont de Dinechin, 1968
Senegal		2.5						Richard *ea*, 1989
France		3.8	5.4	0.1	0.2			Loué, 1963

.../...

Table 7.1. Continued.

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Magnesium								
Mali		2.8	3.0	0.9	1.3			Jenny, 1974
		2.1	2.6	0.8	1.4			Jenny, 1974
		1.9	2.6	0.8	1.0			Traoré, 1974
Nigeria		1.7		1.0				Jones, 1976
Nigeria (south)				1.0	1.4			Kang *ea*, 1977
		1.1						Balasubramanian & Nnadi, 1980
				0.9				Dupont de Dinechin,1968
Senegal			2.2					Richard *ea*, 1989
	leaf blades		2.8					Richard *ea*, 1989
France		1.9	3.3	1.1	1.3			Loué, 1963
Netherlands						1.5	1.7	Schröder & Dilz, 1987
Sulphur								
Mali		0.6	0.8	1.0	1.3			Jenny, 1974
		0.5	0.9	0.7	1.7			Jenny, 1974
		0.4	0.7	0.7	0.9			Traoré, 1974
Nigeria		1.2						Balasubramanian & Nnadi,'81
Australia				0.9	1.1			Thiagalingam *ea*, 1991
Sodium								
Senegal			0.6					Richard *ea*, 1989
	leaf blades		2.0					Richard *ea*, 1989

7.3 Three quandrant figures

7.3.1 Nitrogen

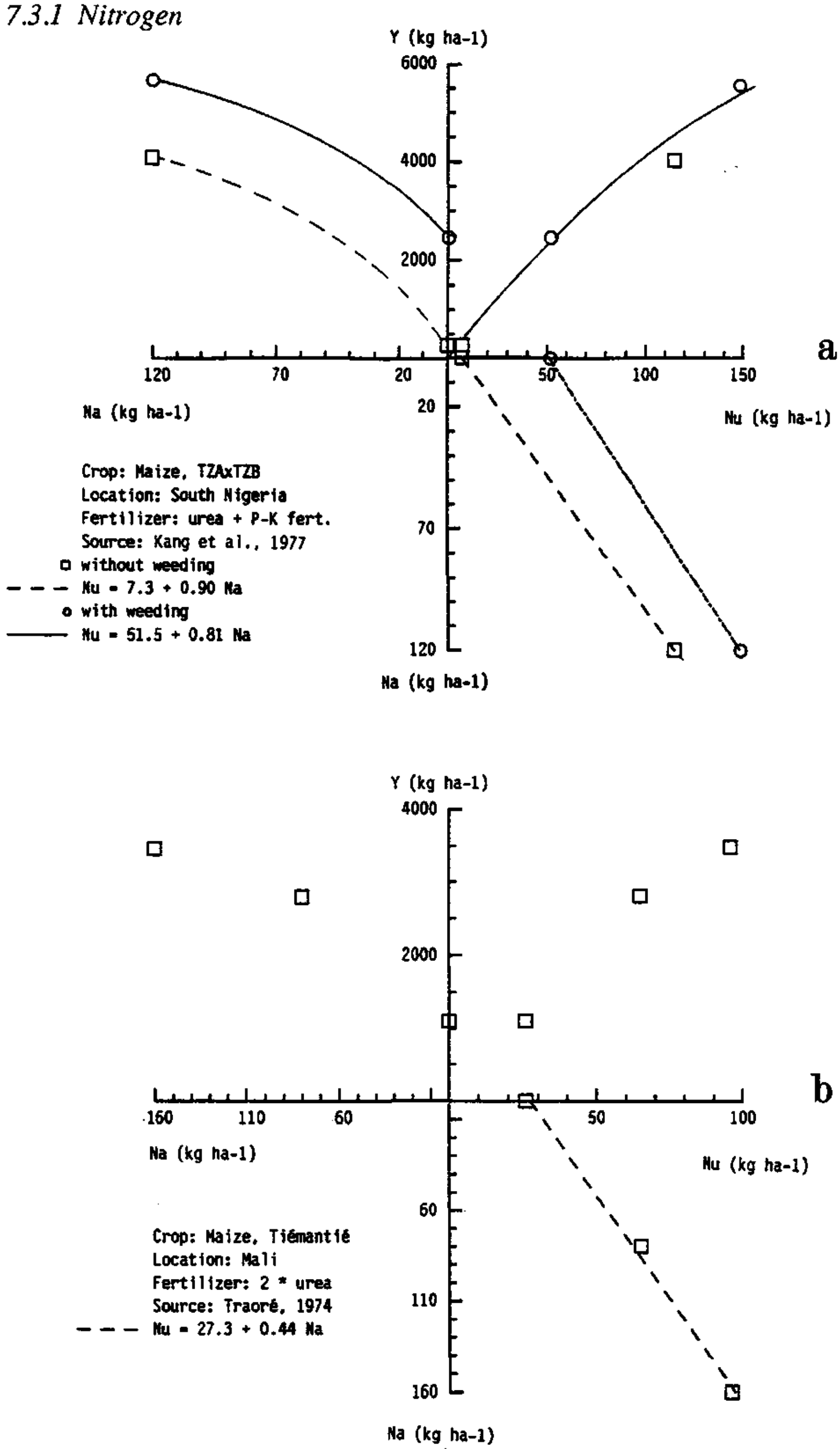


Figure 7.2. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield.*

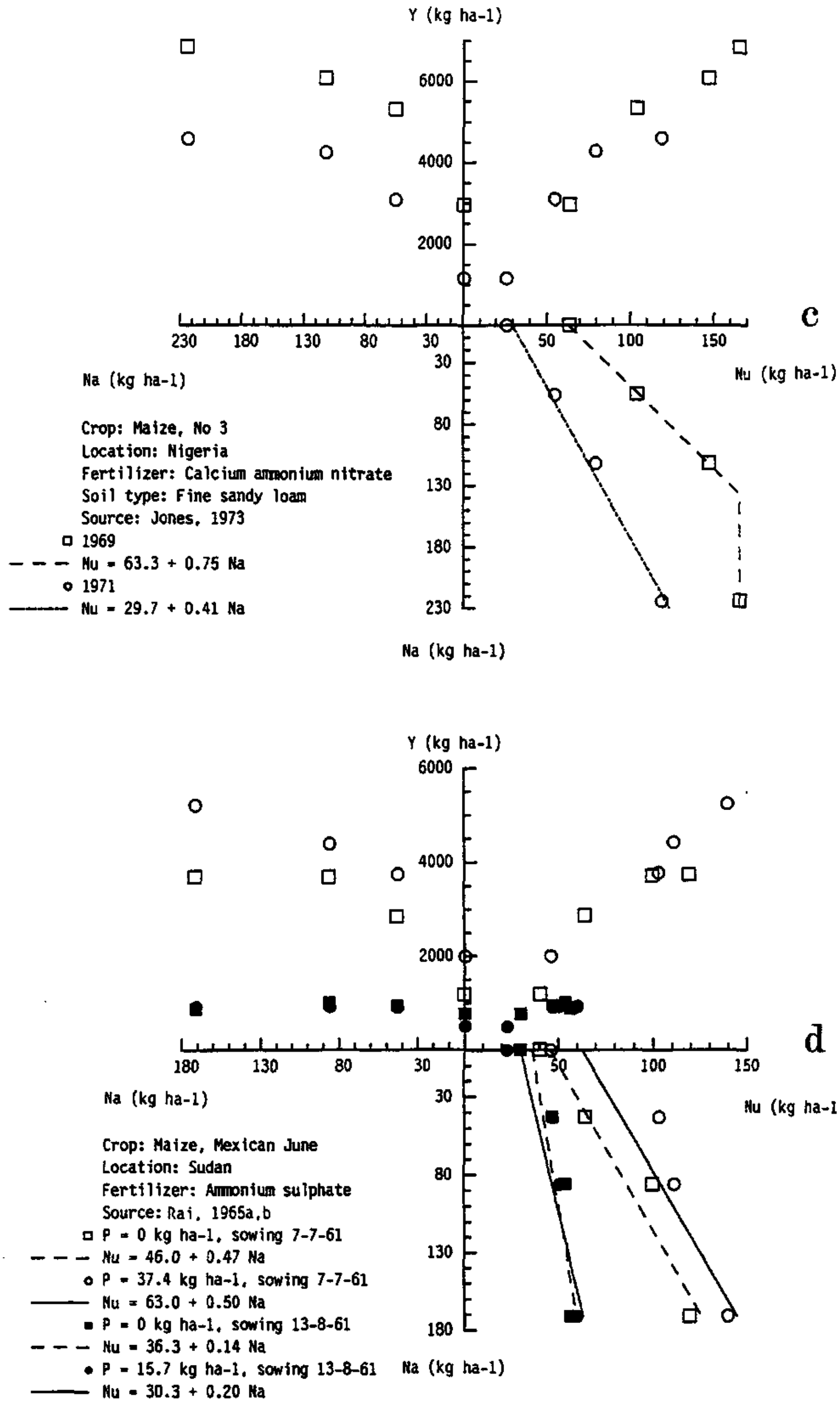
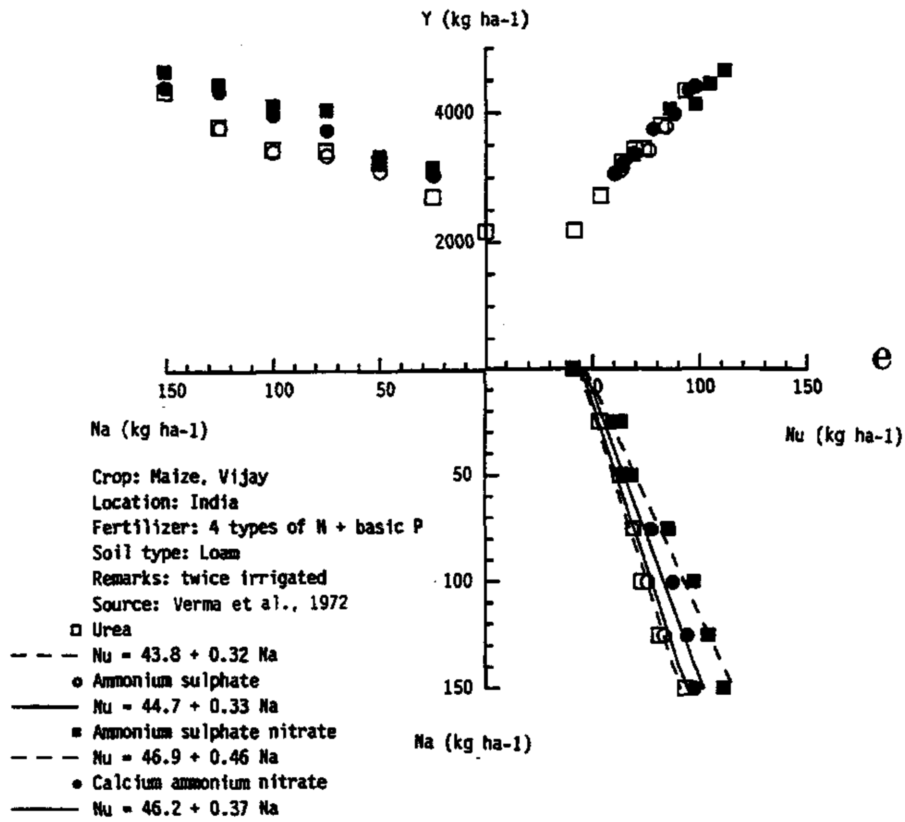


Figure 7.2. Continued.



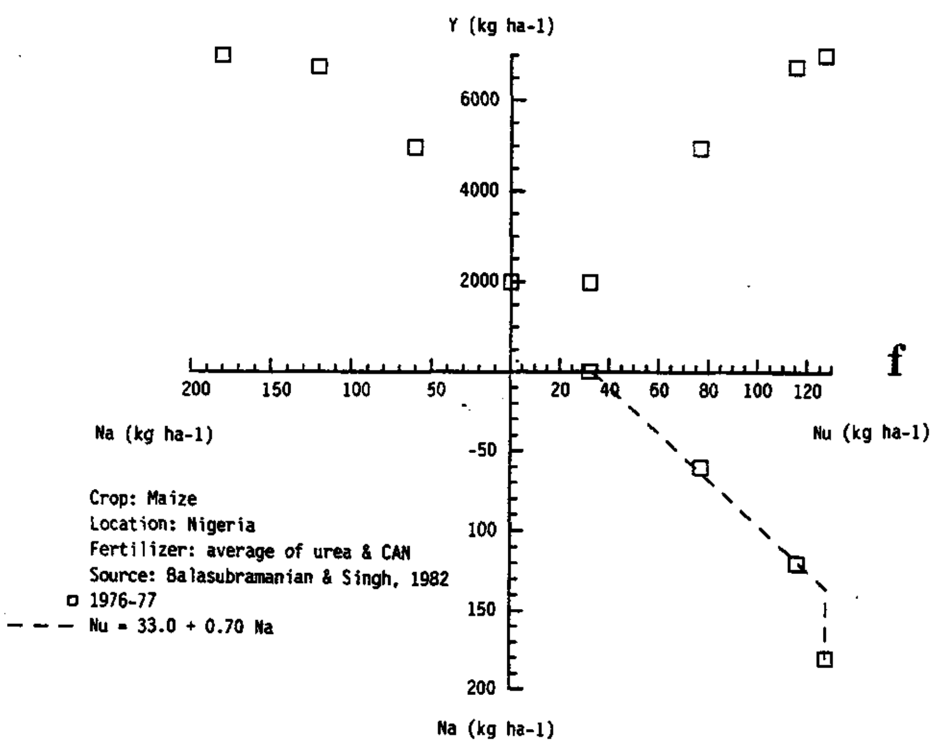


Figure 7.2. Continued.

7.3.2 Phosphorus

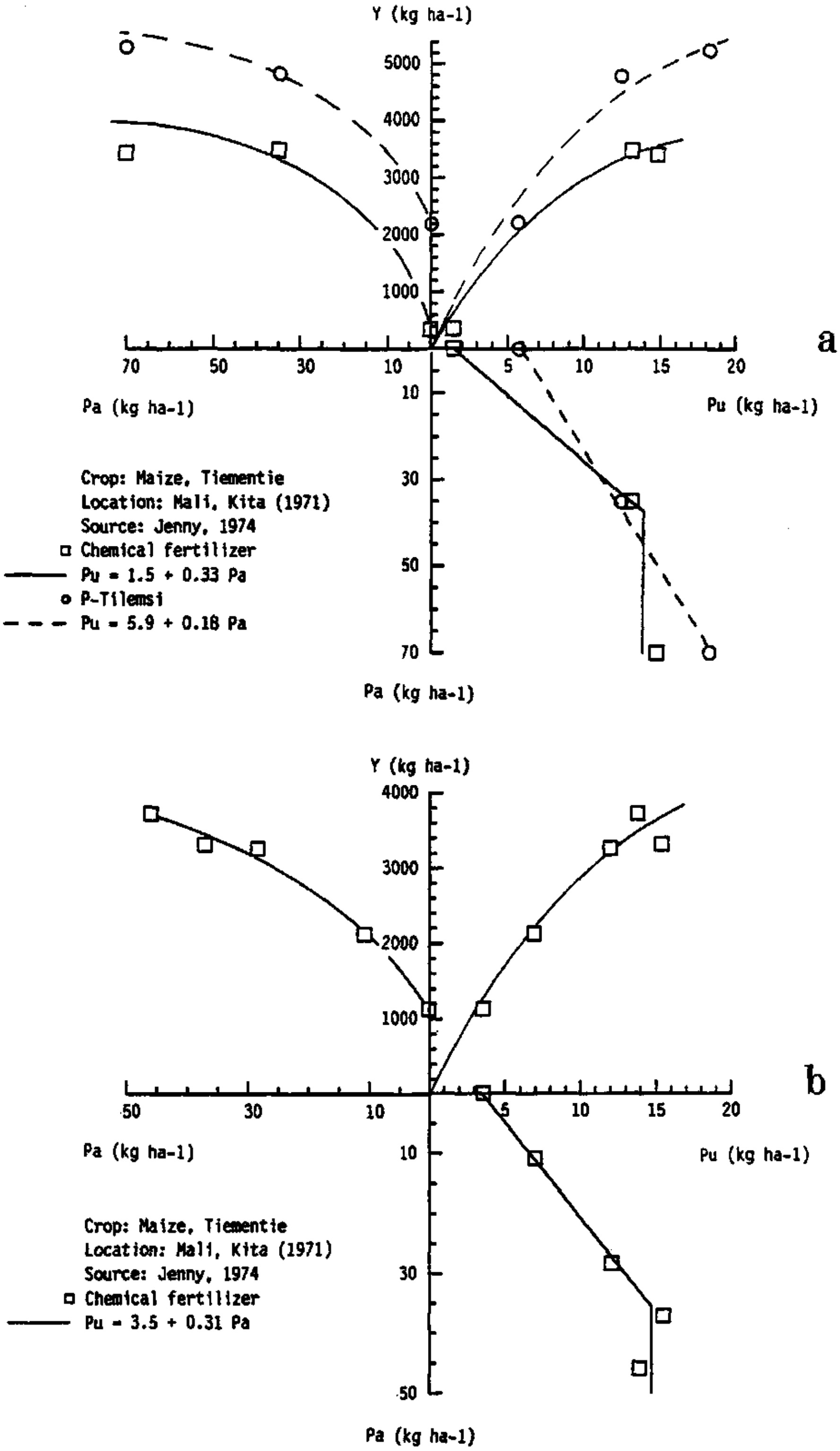


***Figure 7.3**. Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*

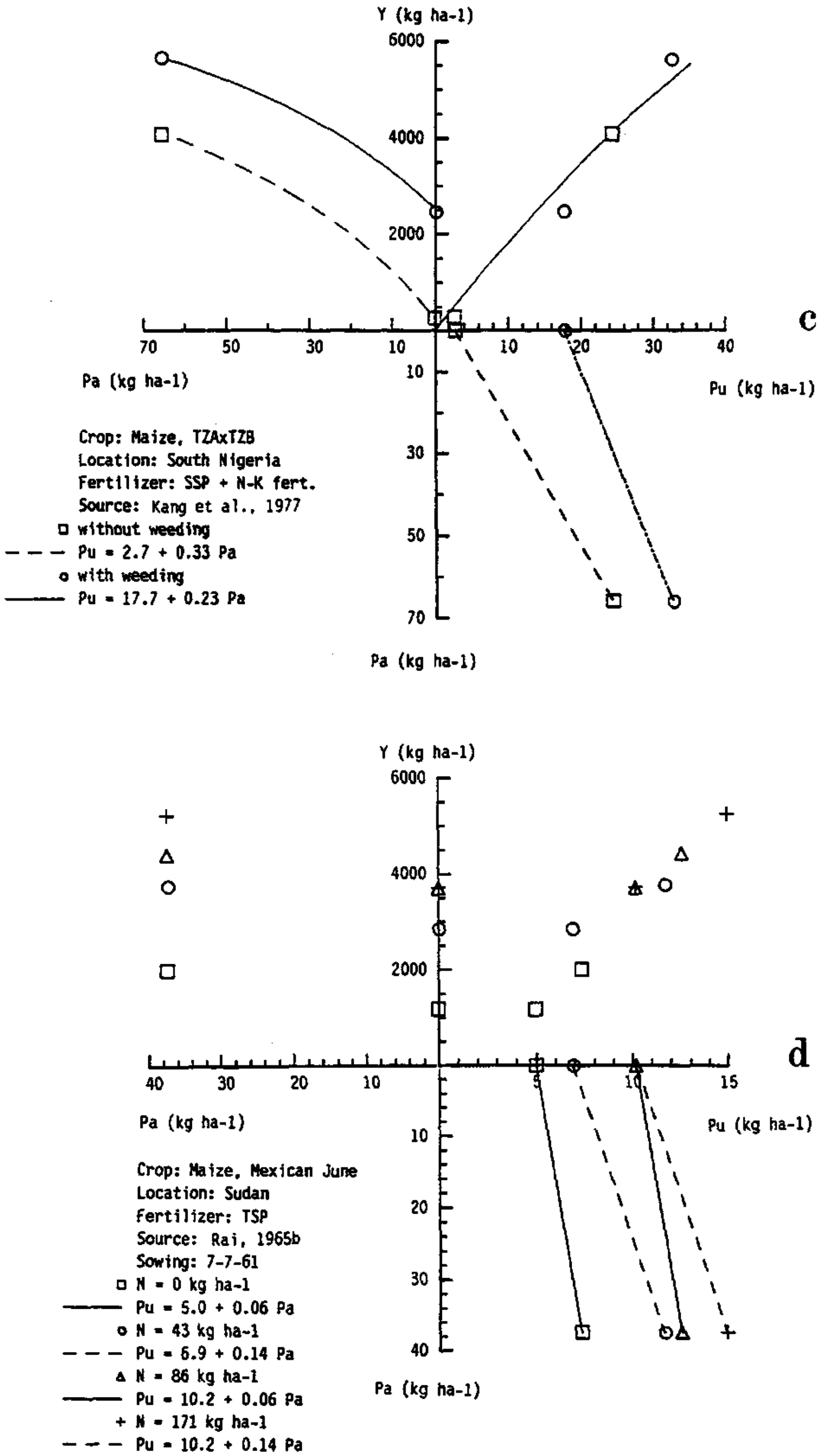


Figure 7.3. Continued.

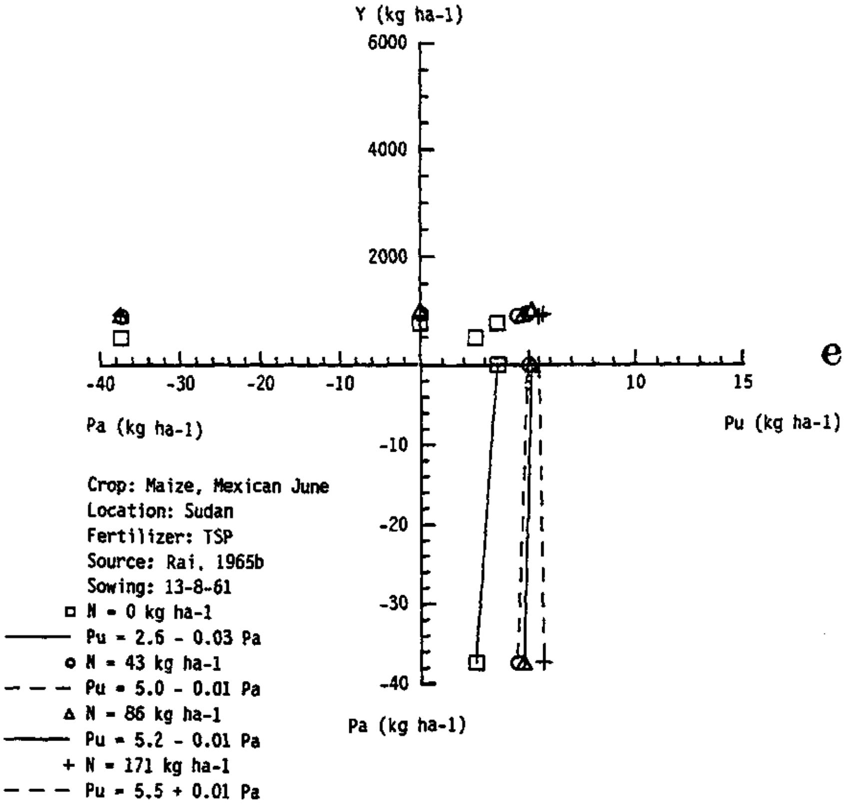


Figure 7.3. Continued.

7.3.3 Potassium

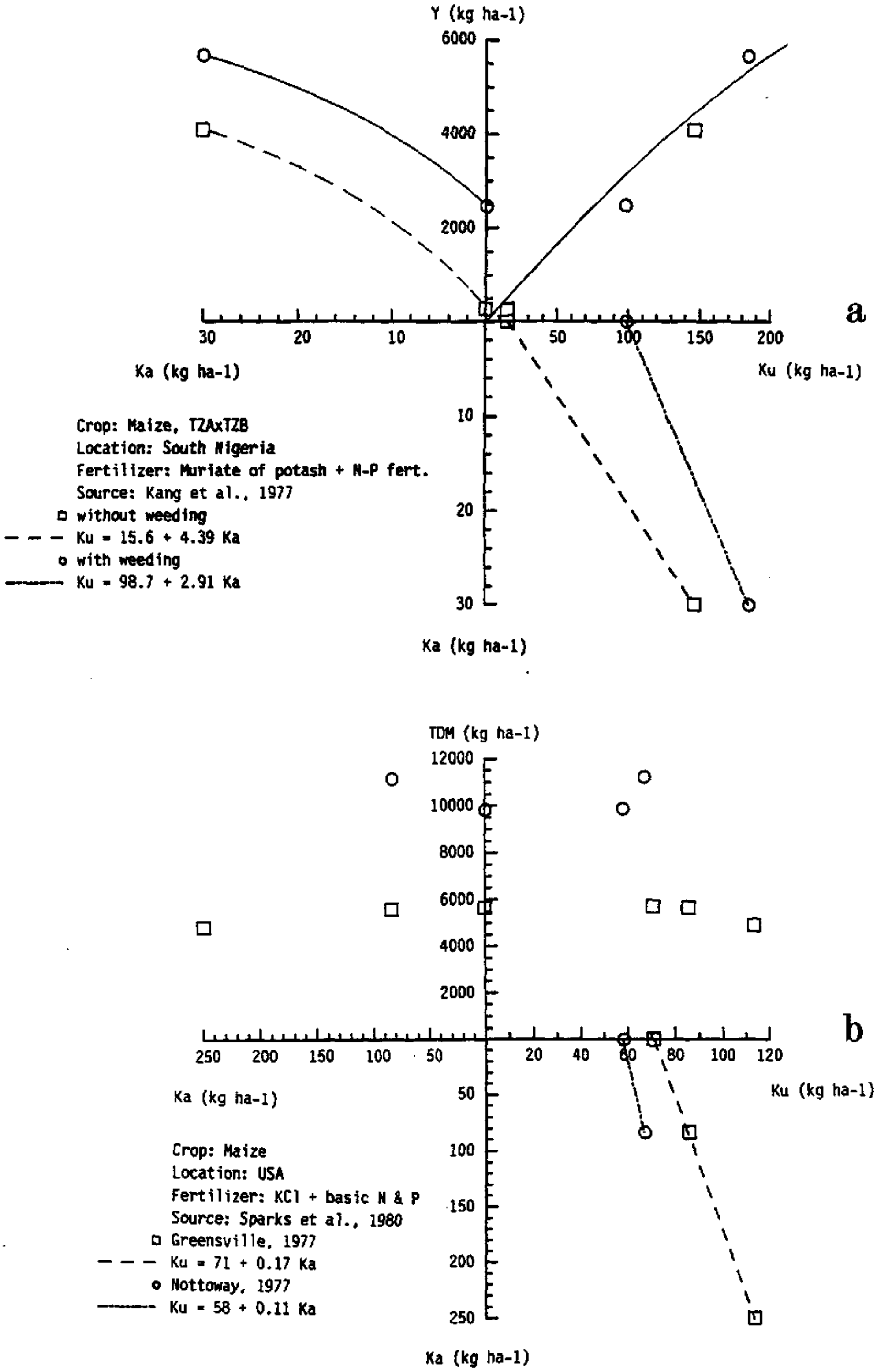


***Figure 7.4.** Relation between total potassium content (K_u) and yield (Y), that between potassium application (K_a) and potassium content, and that between potassium application and yield.*

7.4 Nutrient content as related to yield

With respect to the initial Y/N-content and T/K-content, no differences can be observed between locations (Figures 7.5 and 7.7). For that of phosphorus, however, location and soil acidity play obviously a role (Figure 7.6).

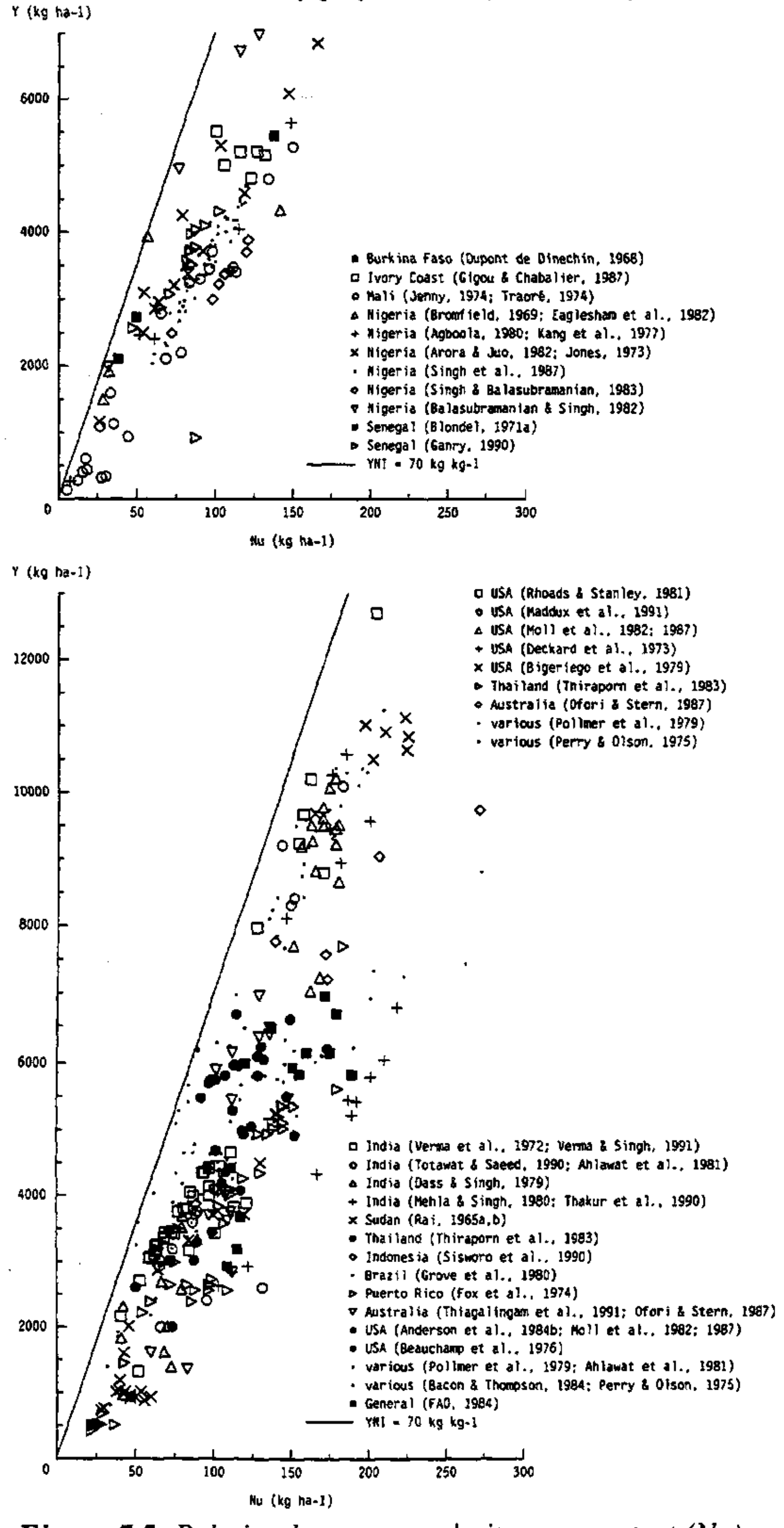


Figure 7.5. Relation between total nitrogen content (N_U) and yield (Y) of maize, a) in West Africa and b) elsewhere; YNI = initial slope.

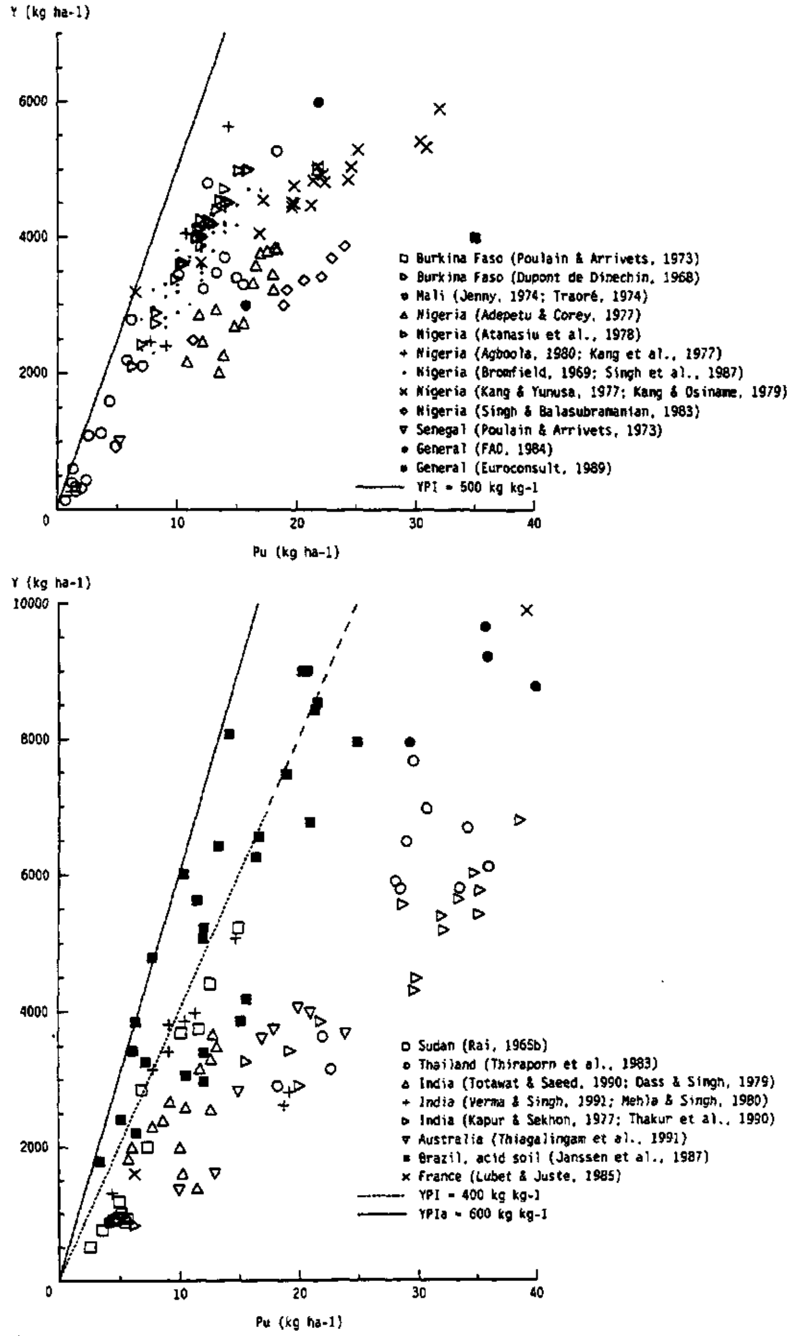


***Figure 7.6.** Relation between total phosphorus content (P_u) and yield (Y) of maize, a) in West Africa and b) elsewhere; YPI = initial slope; YPIa = initial slope for acid soils.*

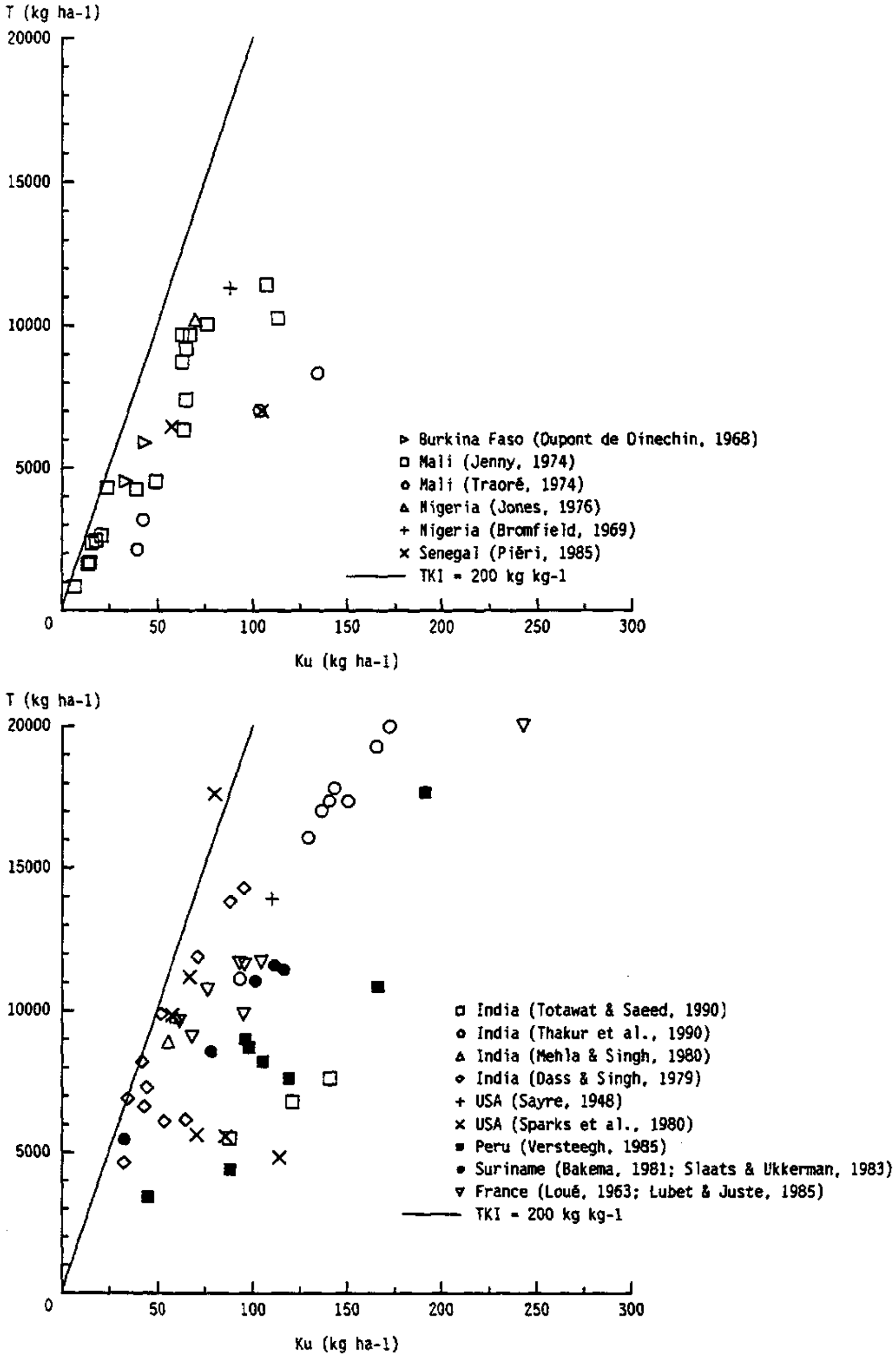


Figure 7.7. *Relation between total potassium content (K_u) and total aboveground dry matter (T) of maize, a) in West Africa and b) elsewhere; TKI = initial slope.*

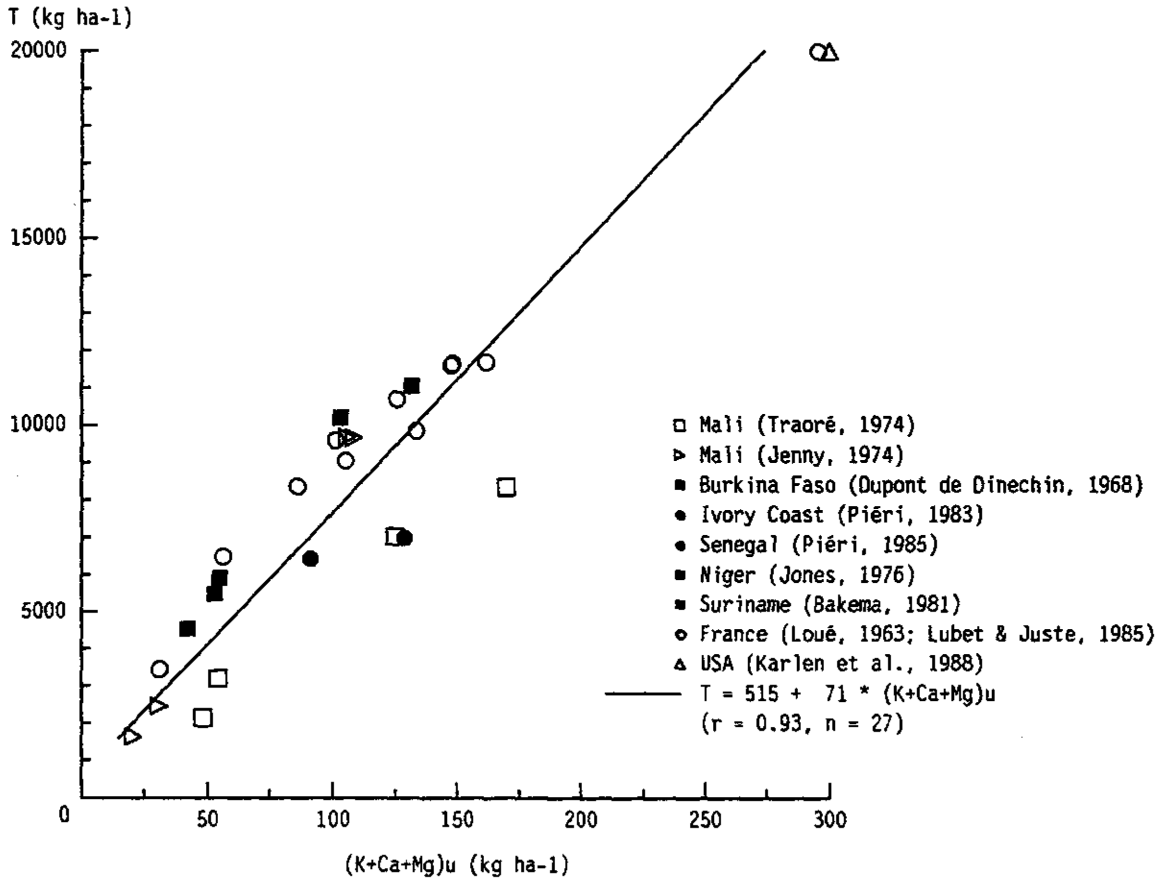


Figure 7.8. *Relation between the combined content of potassium, calcium and magnesium $(K+Ca+Mg)_u$ and total above-ground dry matter (T) in maize. Line represents average regression line.*

7.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 7.9; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

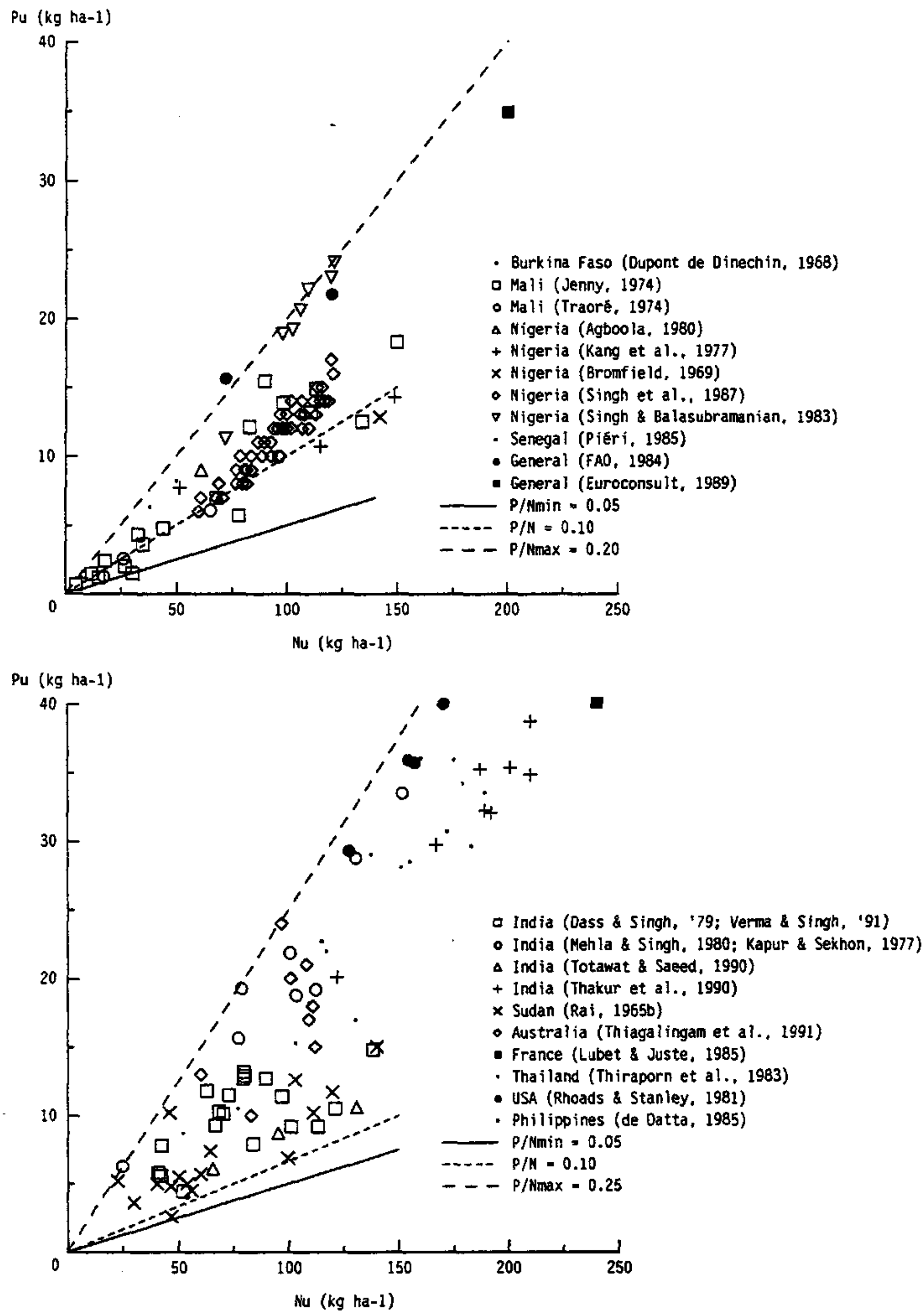


Figure 7.9. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of maize, a) in West Africa and b) elsewhere.*

7.6 Relations among relative post-anthesis nutrient uptake values of N, P and K

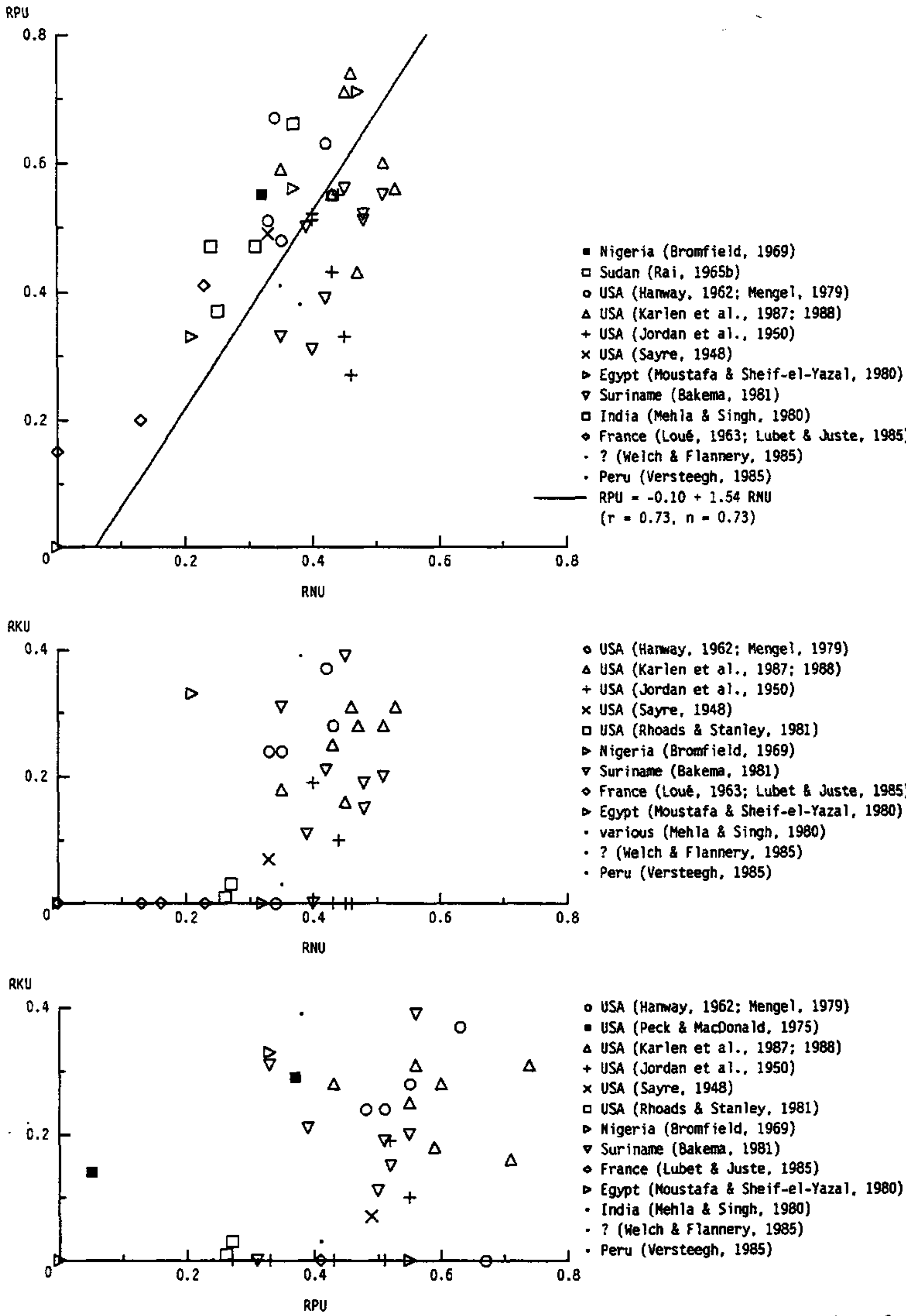


Figure 7.10. *Relationship between relative post-anthesis nutrient uptake in maize of a) nitrogen and phosphorus, b) nitrogen and potassium and c) phosphorus and potassium. Line represents average regression line.*

7.7 Nutrient harvest indices

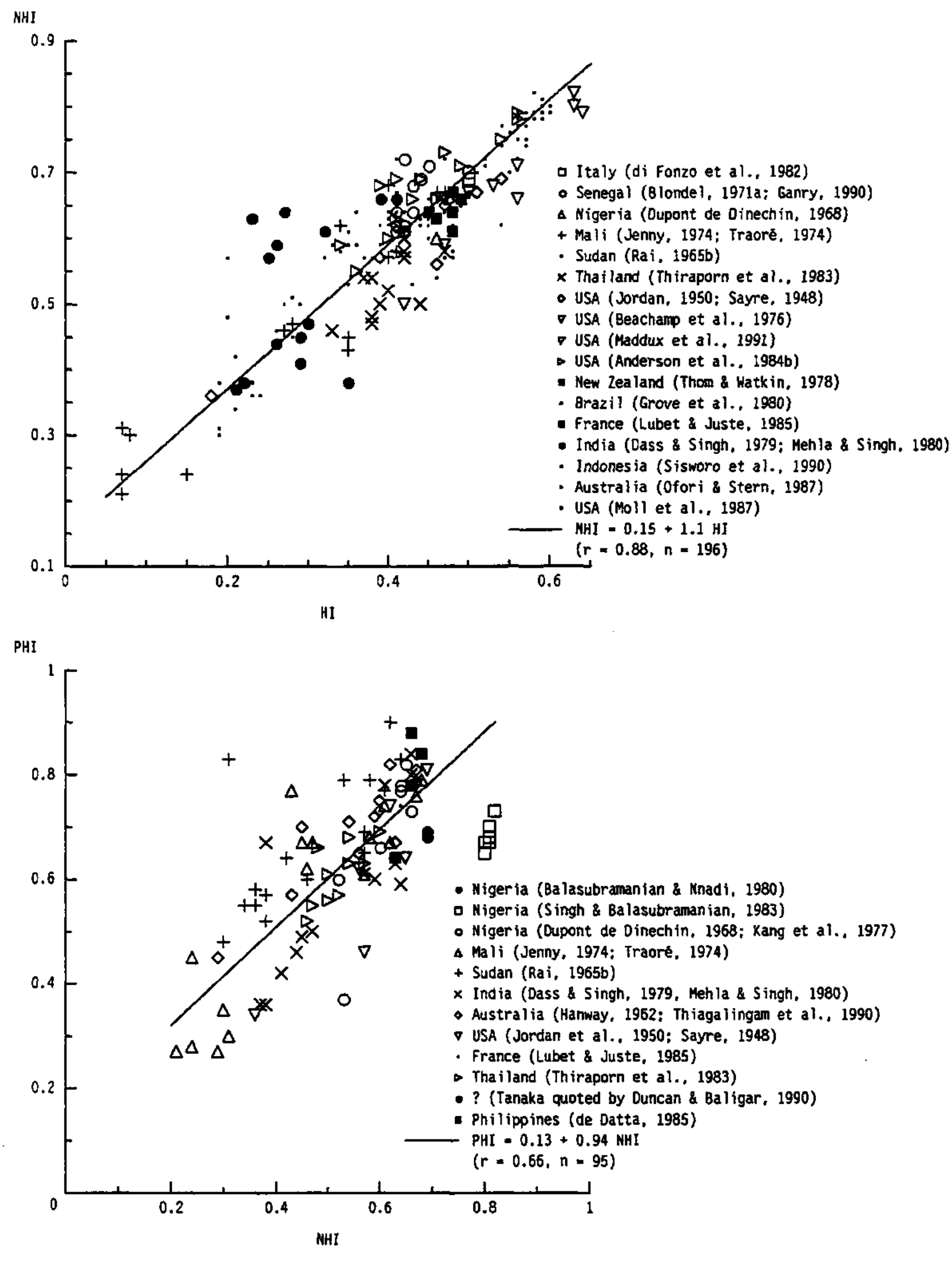


Figure 7.11. *Relation between a) harvest index and nitrogen harvest index and b) nitrogen harvest index and phosphorus harvest index of maize. Line represents average regression line.*

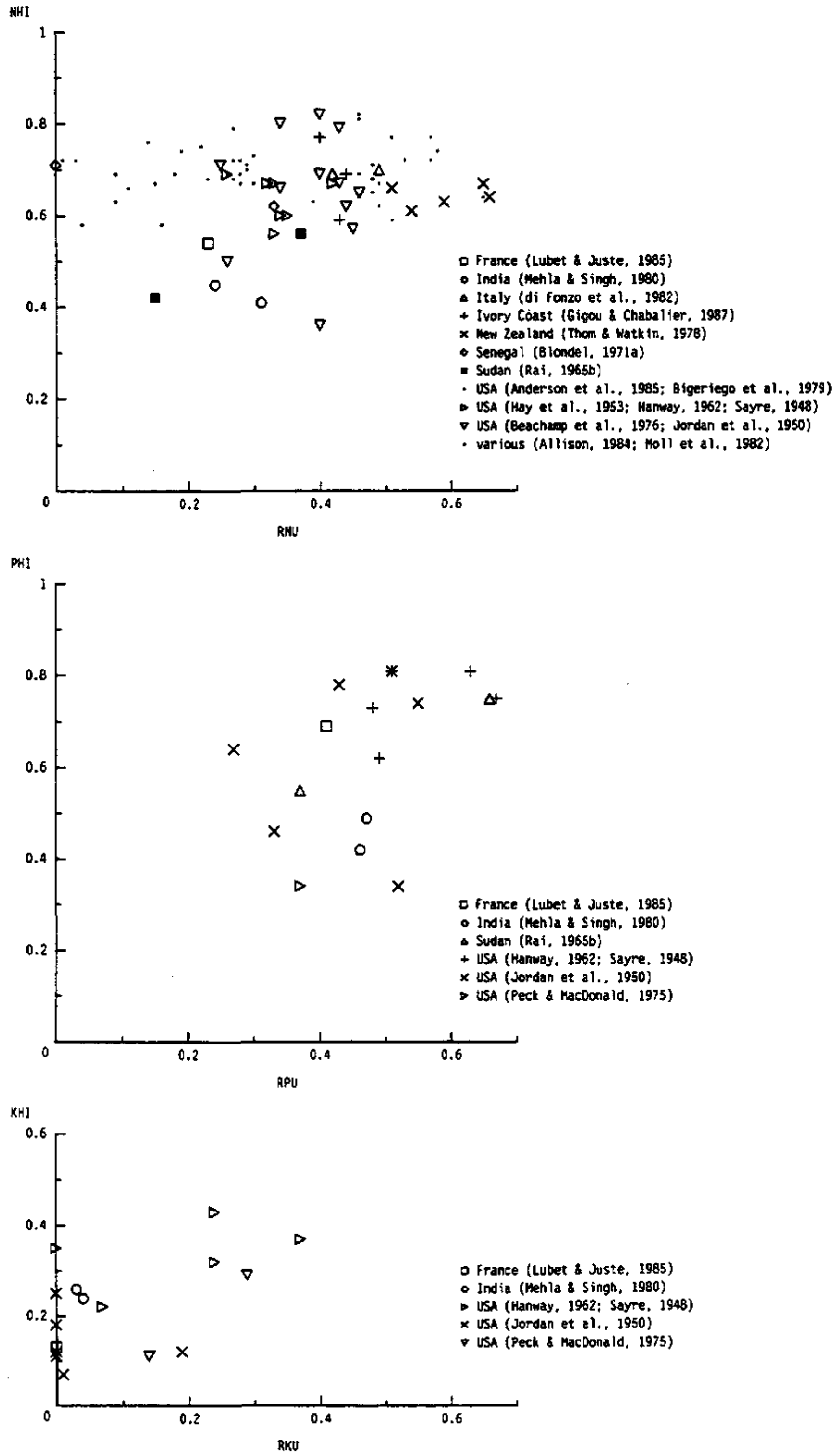


Figure 7.12. *Relation between relative post-anthesis nutrient uptake and nutrient harvest index in maize for a) nitrogen, b) phosphorus and c) potassium.*

8. RICE

8.1 Dry matter distribution

The probability curve of reported harvest indices (HI) for irrigated rice in Figure 8.1, and average HI for deep-water (floating) rice is listed in Table 8.1.

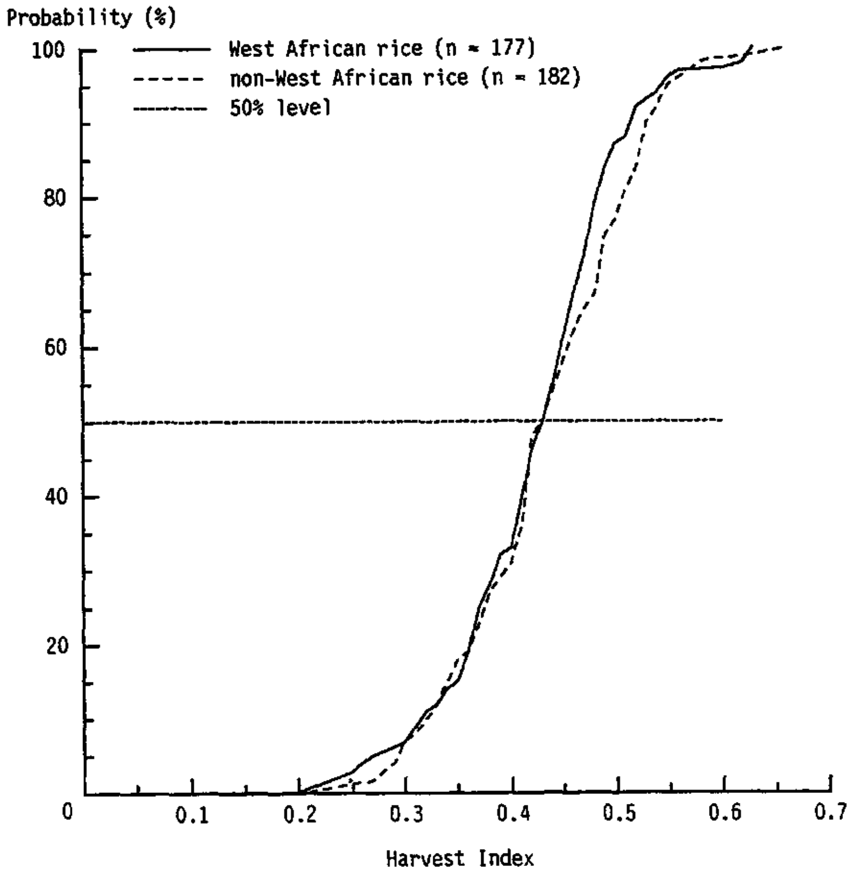


Figure 8.1. Harvest index distribution of rice under different conditions.

Sources West Africa: Arora & Juo, 1972; Beye, 1973a, 1974; Blondel, 1971a,b; Bredero, 1966; Jenny, 1974; Koopmans, 1990; Siband, 1972; Siband & Diatta, 1974; Traoré, 1974;

Elsewhere: Agarwal, 1980; Deshpande et al., 1983; Fageria et al., 1982; Garcia & Garrity, 1991; Garrity et al., 1990; Kondo et al., 1989; Koyama & Chammek, 1971; Mahapatra & Pande, 1972; Majundar, 1973; Makarim et al., 1991; Muthuswamy et al., 1973; Palmer et al., 1990; Reddy & Patrick, 1976; 1978; Saheb et al., 1990; Schnier et al., 1990; Singh & Mogdal, 1978, 1979; Singh & Singh, 1987a,b; Sisworo et al., 1990;

Not included here, but for analysis of HI (Table 2.4) additionally used: de Datta, 1985; Sharma & Mittra, 1991; Sims & Place, 1968; Tokunaga, 1991.

Table 8.1. *Average harvest indices (grain/total aboveground biomass) and their range in floating rice in Mali. n: number of observations; each line corresponds to one data set.*

Variety	mean	range	n	year	remarks	Source
DM16	0.19	0.16-0.21	7	1985	HWL	ADRAO, 1986
DM16	0.23	0.19-0.25	10	1985	HWL	ADRAO, 1986
DM16	0.25	0.18-0.32	10	1984	HWL	ADRAO, 1986
DM16	0.23		1	1985	MWL	ADRAO, 1986
Kao Gaew	0.19		1	1985	MWL	ADRAO, 1986
Kao Gaew	0.27	0.25-0.28	2	1984	MWL-NF	ADRAO, 1985
Kao Gaew	0.25	0.19-0.32	16	1984	MWL-WF	ADRAO, 1985
FRRS-43-3	0.18		1	1985	MWL	ADRAO, 1986

8.2 Concentration of major elements

With respect to the data in Table 8.2, the following remark may be made. The nutrient concentrations reported by Beye (1974, 1973b, 1973a) differ considerably from others. One of the reasons is that his results refer to an acid to very acid soil. As the soils in the Fifth region of Mali are not acid, these results are thus not taken into account for assessment of the minimum concentration.

Table 8.2. *Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total aboveground biomass of rice at maturity; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	PADDY min	PADDY max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
Gambia		7.0						Russo, 1986
Mali	IR8	5.2	7.8	11.0	14.2	7.6	10.0	Jenny, 1974
	IR8			9.7	13.0			Traoré, 1974
	IR8	5.0	6.8	11.3	13.6			Traoré, 1974
Nigeria	BG79	4.1	5.8	9.9	11.7			Bredero, 1965
	BG79	8.1	12.4	12.4	13.8			Bredero, 1965
Senegal	T(N)1, 69-70	3.5	6.4	11.1	12.6			Beye, 1974
	T(N)1, 1970	8.1	11.9	13.8	15.6			Beye, 1974
	T(N)1, 70-71	5.9	12.6	9.6	11.0			Beye, 1974
	T(N)1, 1971	7.0	15.9	12.5	13.2			Beye, 1974
	T(N)1, 63-83	7.2	7.3		12.5			Blondel, 1971a
	IR8, P-fert.	5.9	13.9					Beye, 1973b
	IR8, N-fert.	5.1	6.9					Beye, 1973b
	I Kong Pao			9.5	15.2	8.3	11.2	Siband, 1972
	IKP					9.3	12.4	Siband, 1972
	IKP, no fert.			8.8	9.6			Siband & Diatta
	IKP, N-fert.			8.2	13.8			1974
	IKP, no fert.			8.4	11.6	7.0	9.1	Siband & Diatta
	IKP, N-fert.			9.8	12.8	8.0	9.6	1974
	IKP, N-fert.			10.3	12.9	7.5	9.6	Siband & Diatta
	N-fert.	5.1	10.4	11.3	15.8			1974
			6.4					Richard ea, 1989

.../...

Table 8.2. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	PADDY min	PADDY max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
General		4		10				van Keulen, 1977
				12.8				Sinclair & de
								Wit, 1975
		5.1		13.6				RFMC, 1980
		5.1		14.9				Euroconsult, 1989
Australia		3.8	5.1	8.3	9.6			Humphreys *ea*,1987
China				14.5	18.2			Jun *ea*, 1991
				16.5	17.6			Jun *ea*, 1991
		9.0	13.0	14.0	15.8			De-Yin & Bao,1985
India		8.5	9.8	9.9	19.0			Nair & Ayer, 1983
		5.5	6.4	14.4	16.7	9.1	10.6	Agarwal, 1980
		6.0	9.6	9.9	11.7	8.0	10.0	Mahapatra &
		6.1	8.9	8.7	11.7	7.0	9.7	Pande,
		6.1	7.7	9.3	11.8			1972
	upland	5.3	6.4	11.2	12.8			Singh & Modgal,
		5.4	6.2	10.6	12.4			1979
		11.8	13.7	16.0	21.0			Thandapani & Rao,
								1974
Indonesia		7.9	8.7	12.1	13.3	9.2	10.5	Sisworo *ea*, 1990
		7.9	9.3	12.2	13.3	9.2	10.8	Sisworo *ea*, 1990
Japan			6.4	10.6				de Datta, 1981
Madagascar	1968			10.9	12.3			Velly, 1972
	1968-69			12.4	15.8			Velly, 1972
	1969			11.2	12.5			Velly, 1972
Philippines			9.0		14.6			de Datta & Mik-
								kelsen, 1985
		5.3		10.9				de Datta, 1981
		6.0	6.2	10.7	12.7			Yoshida, 1981
Phosphorus								
Ivory C.	IDSA6					0.9	1.1	Koopmans, 1990
Ivory C.	IDSA6					0.5	1.3	Koopmans, 1990
Ivory C.	IDSA6					0.7	1.3	Koopmans, 1990
Ivory C.	IDSA6					0.5	1.1	Koopmans, 1990
Mali	IR8	0.8	1.3	2.3	2.7	1.3	1.8	Jenny, 1974
	IR8			1.7	2.5			Traoré, 1974
	IR8	0.9	1.1	1.5	2.1			Traoré, 1974
Nigeria	BG79	0.7	1.2	2.4	2.7			Bredero, 1965
	BG79	0.6	1.1	2.4	2.8			Bredero, 1965
	BG79	0.4	1.0	2.1	2.4	2.4	3.4	Bredero, 1966
Senegal	T(N)1, 1969	1.2	2.4					Beye, 1974
	T(N)1, 69-70	0.8	1.9	2.0	2.4	1.5	2.2	Beye, 1974
	T(N)1, 1970	1.1	1.5	2.4	2.7			Beye, 1974
	T(N)1, 70-71	1.3	1.4	1.6	1.7			Beye, 1974
	T(N)1, 1971	2.0	2.6	2.4	2.6			Beye, 1974
	IR8, P-fert.	0.3	1.0					Beye, 1973b
	IR8, N-fert.	0.7	1.0					Beye, 1973b
			1.1					Richard *ea*, 1989

.../...

Table 8.2. Continued.

COUNTRY	REMARKS	STRAW min	STRAW max	PADDY min	PADDY max	TOTAL min	TOTAL max	SOURCE
Phosphorus								
Senegal	IR8 1970	0.4	1.4	2.0	4.5			Beye, 1973a*
	IR8 1971 dry	0.2	0.8	1.3	3.6			Beye, 1973a*
	IR8 1971 wet	0.6	1.3	1.6	4.0	1.5	3.6	Beye, 1973a*
	I Kong Pao			1.3	1.7	1.3	2.3	Siband, 1972
	I Kong Pao					1.8	2.4	Siband, 1972
	IKP, PK-fert.	0.8	1.7	1.0	2.1			Siband & Diatta, 1974
Brazil						0.8	1.2	Fageria ea, 1982
						0.4	0.7	Fageria ea, 1982
China				3.7	4.1			Jun *ea*, 1991
				3.4	3.6			Jun *ea*, 1991
		1.4	2.9	3.9	4.4			De-Yin & Bao, 1985
General		0.8		2.6				RFMC, 1980
	quotation					0.9	5.2	Bredero, 1966
India		1.0	1.3	2.6	3.0	1.6	2.0	Agarwal, 1980
	1976	1.0	1.4	1.3	1.9			Bhushan & Singh,
		1.1	1.2	1.5	1.7			1979
		0.6	0.8	0.6	0.8	0.6	0.7	Mahapatra &
		0.6	0.7	0.6	0.8	0.6	0.7	Pande,
		0.5	0.8	0.6	0.8			1972
		1.2	1.8	2.6	3.4			Nair & Ayer, 1983
						1.7	2.0	Saheb ea, 1990
	N-applic.	1.9	2.5	2.5	2.7			Singh & Modgal,
	time	1.9	2.5	2.5	2.7			1978
India	variety	1.9	2.7	2.5	2.7			Singh & M., 1978
	ADT 27	0.5	0.6	3.6	3.9			Thandapani & Rao, 1974
Indonesia	quotation			2.2	3.2			Palmer *ea*, 1990
Japan		0.5			2.2			de Datta, 1981
Madagascar	1968			1.3	1.4			Velly, 1972
	1968-69			1.3	1.4			Velly, 1972
	1969			1.4	1.6			Velly, 1972
Philippines		0.3	0.3	1.2	1.3	0.8	0.8	de Datta, 1985
						0.8	1.0	Garrity *ea*, 1990
						1.3	1.5	Garcia & Garrity,
						1.4	1.6	1991
			0.8		2.0			de Datta, 1981
		0.9	1.8	2.0	4.2			Yoshida, 1981
Thailand						0.8	1.6	Koyama & Chammek,
						0.7	2.1	1971
		0.6	1.6	2.0	.32	1.6	2.2	Palmer *ea*, 1990

*: these are P_2O_5 values in the article, but in comparison with all other data, considered as P values.

.../...

Table 8.2. *Continued.*

COUNTRY	REMARKS	STRAW min	STRAW max	PADDY min	PADDY max	TOTAL min	TOTAL max	SOURCE
Potassium								
Ivory C.	IDSA6					9.1	12.6	Koopmans, 1990
Ivory C.	IDSA6					9.0	12.5	Koopmans, 1990
Ivory C.	IDSA6					9.8	12.3	Koopmans, 1990
Ivory C.	IDSA6					8.8	11.6	Koopmans, 1990
Mali	IR8	20.0	26.5	5.1	5.6	14.9	18.8	Jenny, 1974
	IR8			3.8	5.0			Traoré, 1974
	IR8	17.9	21.4	4.0	5.2			Traoré, 1974
Nigeria	BG79	24.5	30.5	3.8	4.2			Bredero, 1965
	BG79	19.9	28.9	3.6	4.0			Bredero, 1965
Senegal	T(N)1, 1969	18.8	25.6					Beye, 1974
	T(N)1, 69-70	18.8	29.3	4.5	9.7			Beye, 1974
	T(N)1, 1970	2.7	12.0	2.9	3.2			Beye, 1974
	T(N)1, 70-71	5.5	10.2	5.0	5.5			Beye, 1974
	T(N)1, 1971	6.6	13.3	5.0	5.3			Beye, 1974
	T(N)1, 1972	16.3	20.0	1.5	1.7			Beye, 1974
	IR8, P-fert.	10.4	13.9					Beye, 1973b
	IR8, N-fert.	13.3	16.4					Beye, 1973b
	I Kong Pao			3.6	4.1	11.4	19.0	Siband, 1972
	IKP					11.5	19.8	Siband, 1972
	IKP, N-fert.					8.8	14.0	Siband & Diatta,
	IKP, PK-fert.	5.2	15.9	3.0	3.9			1974
Brazil						15.9	20.4	Fageria *ea*, 1982
						14.9	17.5	Fageria *ea*, 1982
China				3.3	3.6			Jun *ea*, 1991
				3.9	4.4			Jun *ea*, 1991
		18.0	19.3	2.7	2.7			De-Yin & Bao, 1985
General	quotation					3.3	30.7	Bredero, 1966
India		11.8	13.1	8.4	9.2	8.4	9.2	Agarwal, 1980
		10.1	12.3	4.0	4.5	7.6	8.5	Mahapatra &
		9.9	12.3	3.8	4.5	7.9	8.1	Pande,
		5.8	12.3	2.0	5.8			1972
		17.8	20.1	8.5	9.9			Nair & Ayer, 1983
		9.5	16.7					Ram & Prasad, 1985
						5.1	9.0	Saheb *ea*, 1990
	N-applic.	21.1	23.4	2.1	2.3			Singh & Modgal,
	time	21.6	23.1	2.1	2.3			1978
	variety	21.9	22.7	2.0	2.4			Singh & M., 1978
	ADT 27	24.5	28.0	7.0	8.0			Thandapani & Rao, 1974
Japan		17.0			3.2			de Datta, 1981
Madagascar	1968			2.6	2.8			Velly, 1972
	1968-69			2.1	2.4			Velly, 1972
	1969			2.0	3.1			Velly, 1972
Philippines		17.5	23.5	2.2	2.4	9.2	11.9	de Datta, 1985
		13.6			3.1			de Datta, 1981
		24.3	30.7	2.7	6.8			Yoshida, 1981
Thailand						3.4	15.7	Koyama & Chammek,
						6.6	15.3	1971

.../...

Table 8.2. Continued.

COUNTRY	REMARKS	STRAW min	STRAW max	PADDY min	PADDY max	TOTAL min	TOTAL max	SOURCE
Calcium								
Mali	IR8	2.5	2.7	0.8	1.1			Jenny, 1974
	IR8			0.3	0.5			Traoré, 1974
	IR8	2.7	2.9	0.3	0.6			Traoré, 1974
Senegal	IR8, P-fert.	1.0	1.4					Beye, 1973b
	IR8, N-fert.	1.0	1.6					Beye, 1973b
			2.5					Richard *ea*, 1989
General		1.9			0.6			RFMC, 1980
China				0.1	0.2			Jun *ea*, 1991
				0.2	0.2			Jun *ea*, 1991
India		8.2	9.7	0.4	0.6			Nair & Ayer, 1983
		16.2	18.0	2.9	3.2			Thandapani & Rao, 1974
Japan		3.0		0.3				de Datta, 1981
Philippines			3.2	0.1				de Datta & Mikkelsen, 1985
			3.9		0.5			de Datta, 1981
		2.3	2.9	0.4	0.4			Yoshida, 1981
Magnesium								
Mali	IR8	1.8	1.9	1.4	1.6			Jenny, 1974
	IR8			1.0	1.6			Traoré, 1974
	IR8	1.6	1.9	1.1	1.3			Traoré, 1974
Senegal	IR8, P-fert.	0.5	1.2					Beye, 1973b
	IR8, N-fert.	0.6	1.7					Beye, 1973b
			2.2					Richard *ea*, 1989
China				1.5	1.6			Jun *ea*, 1991
				1.4	1.6			Jun *ea*, 1991
India		1.2	2.0	1.6	2.5			Nair & Ayer, 1983
Japan		1.2		0.7				de Datta, 1981
Philippines			1.6	1.0				de Datta & Mikkelsen, 1985
			2.6		1.1			de Datta, 1981
		2.1	2.7	1.2	1.4			Yoshida, 1981
Sulphur								
Mali	IR8	0.7	1.0	1.0	1.2			Jenny, 1974
	IR8			0.9	1.3			Traoré, 1974
	IR8	0.7	0.9	1.1	1.2			Traoré, 1974
China				1.3	1.6			Jun *ea*, 1991
				1.8	1.9			Jun *ea*, 1991
Philippines		0.4		0.6				de Datta & Mikkelsen, 1985
		0.7			1.0			de Datta, 1981
		0.9	1.0	0.8	0.8			Yoshida, 1981
Sodium								
Senegal			6.0					Richard *ea*, 1989

8.3 Three quandrant figures

8.3.1 Nitrogen

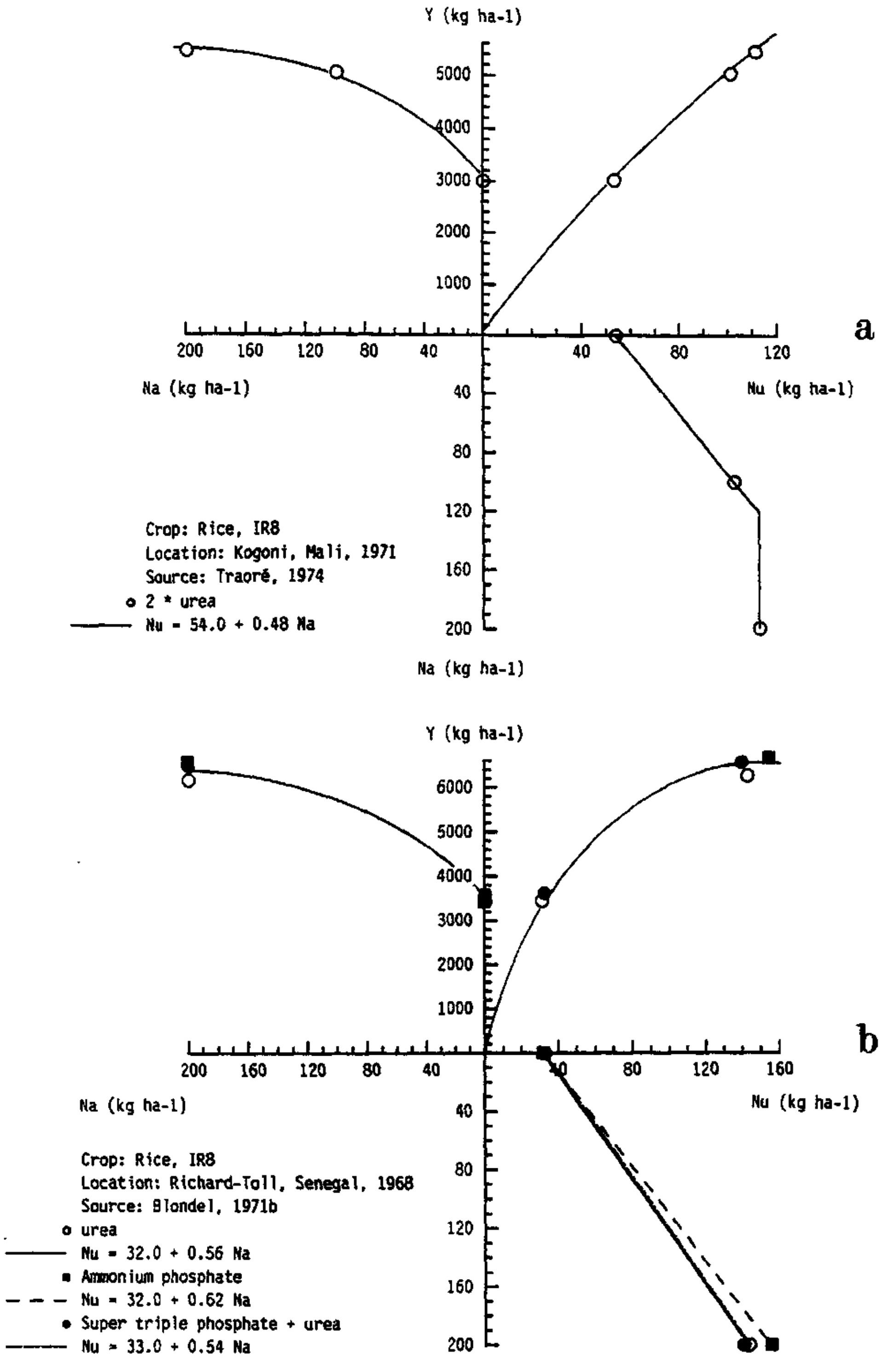


Figure 8.2. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield in rice.*

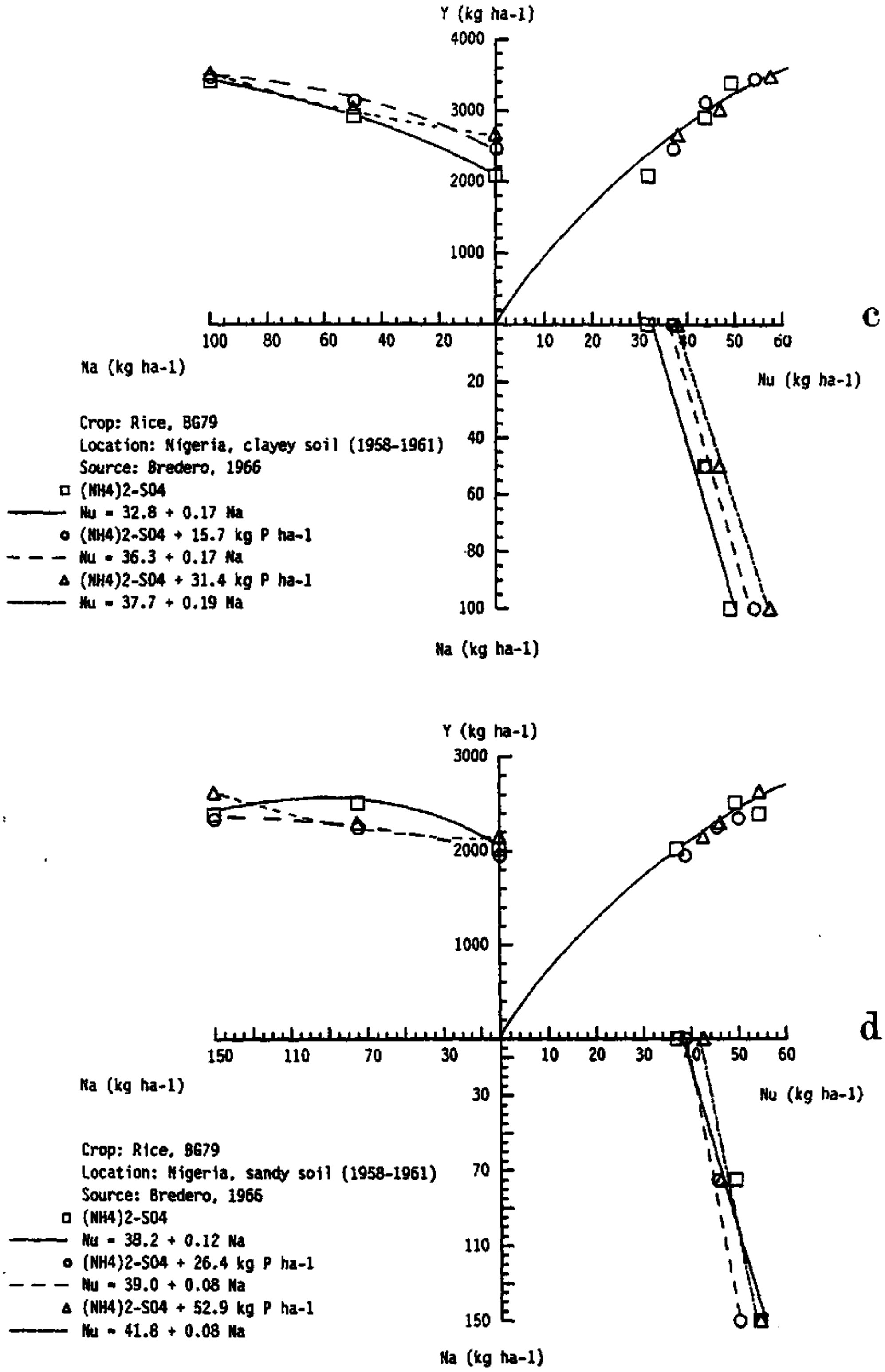
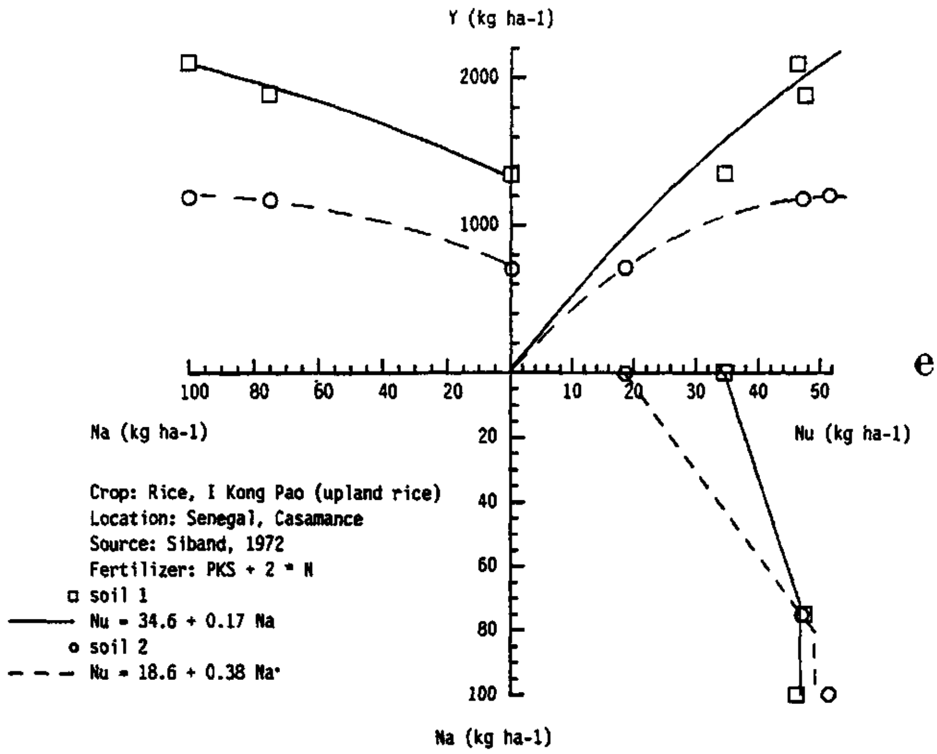


Figure 8.2. Continued.



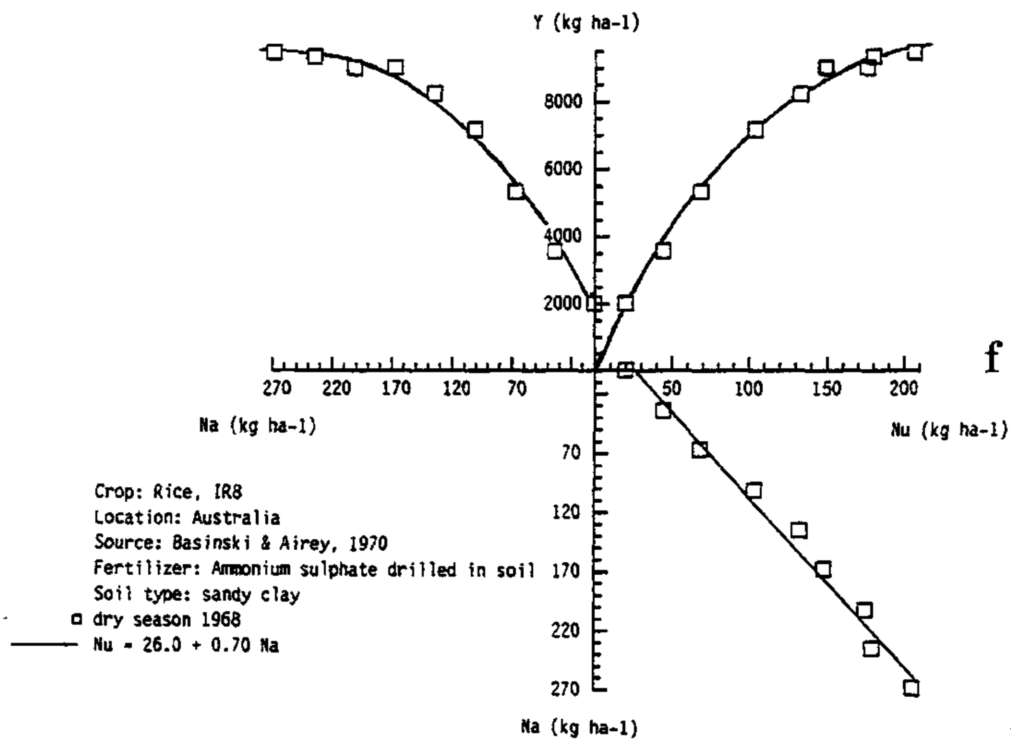


Figure 8.2. Continued.

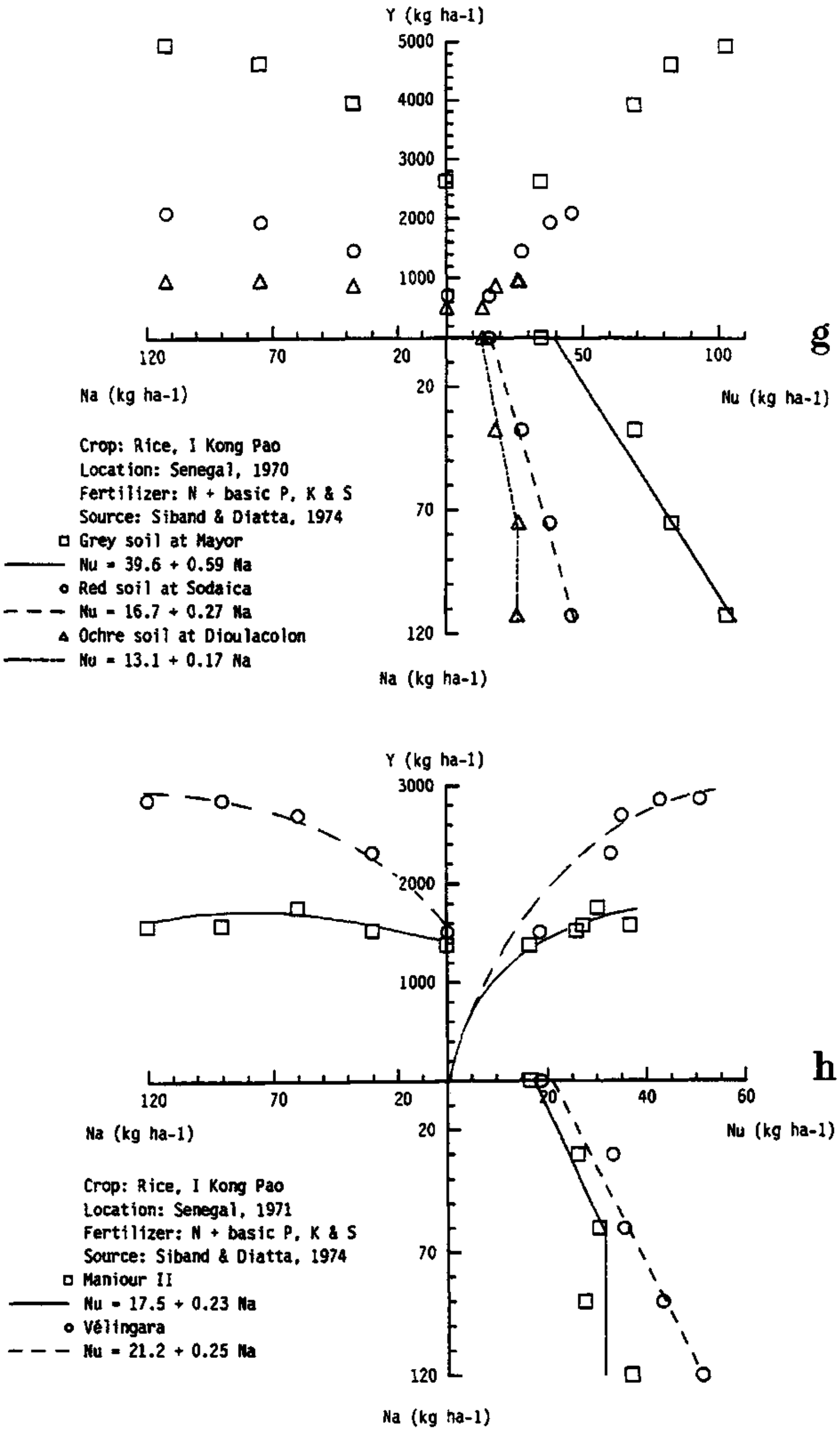
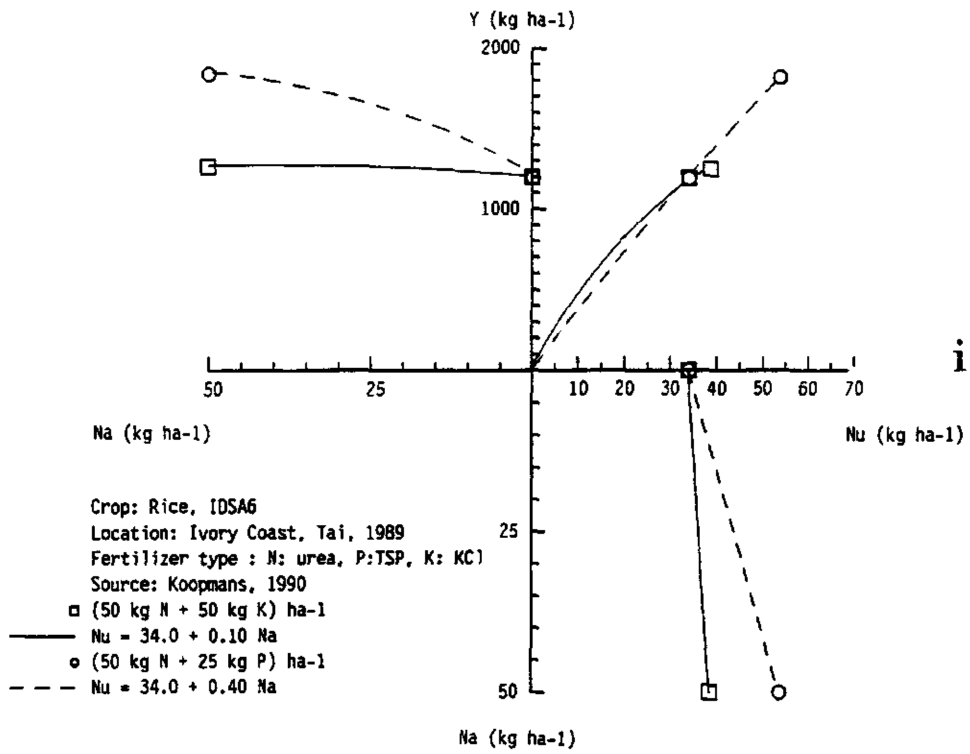


Figure 8.2. Continued.



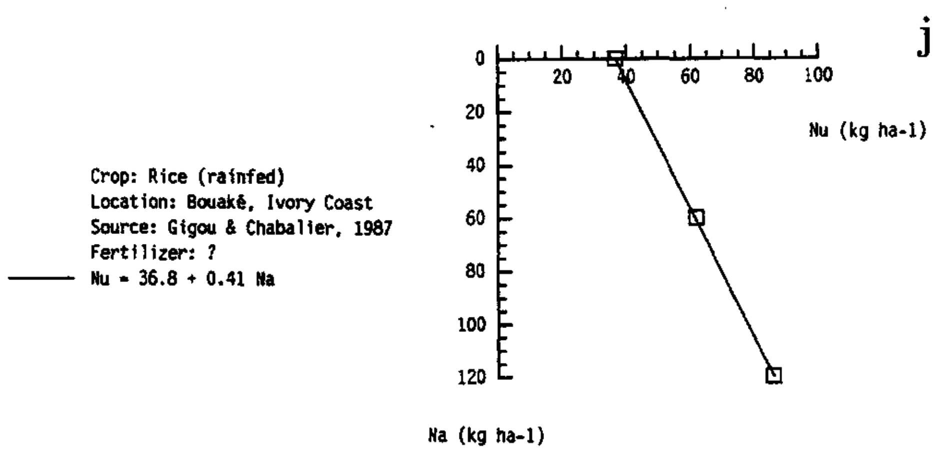


Figure 8.2. Continued.

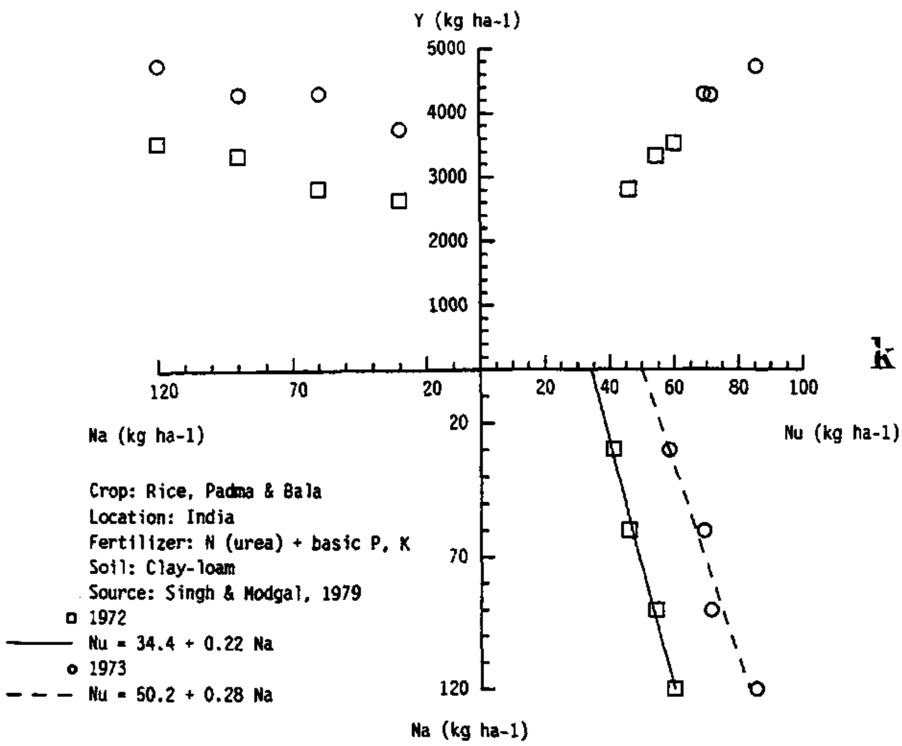


Figure 8.2. Continued.

8.3.2 Phosphorus

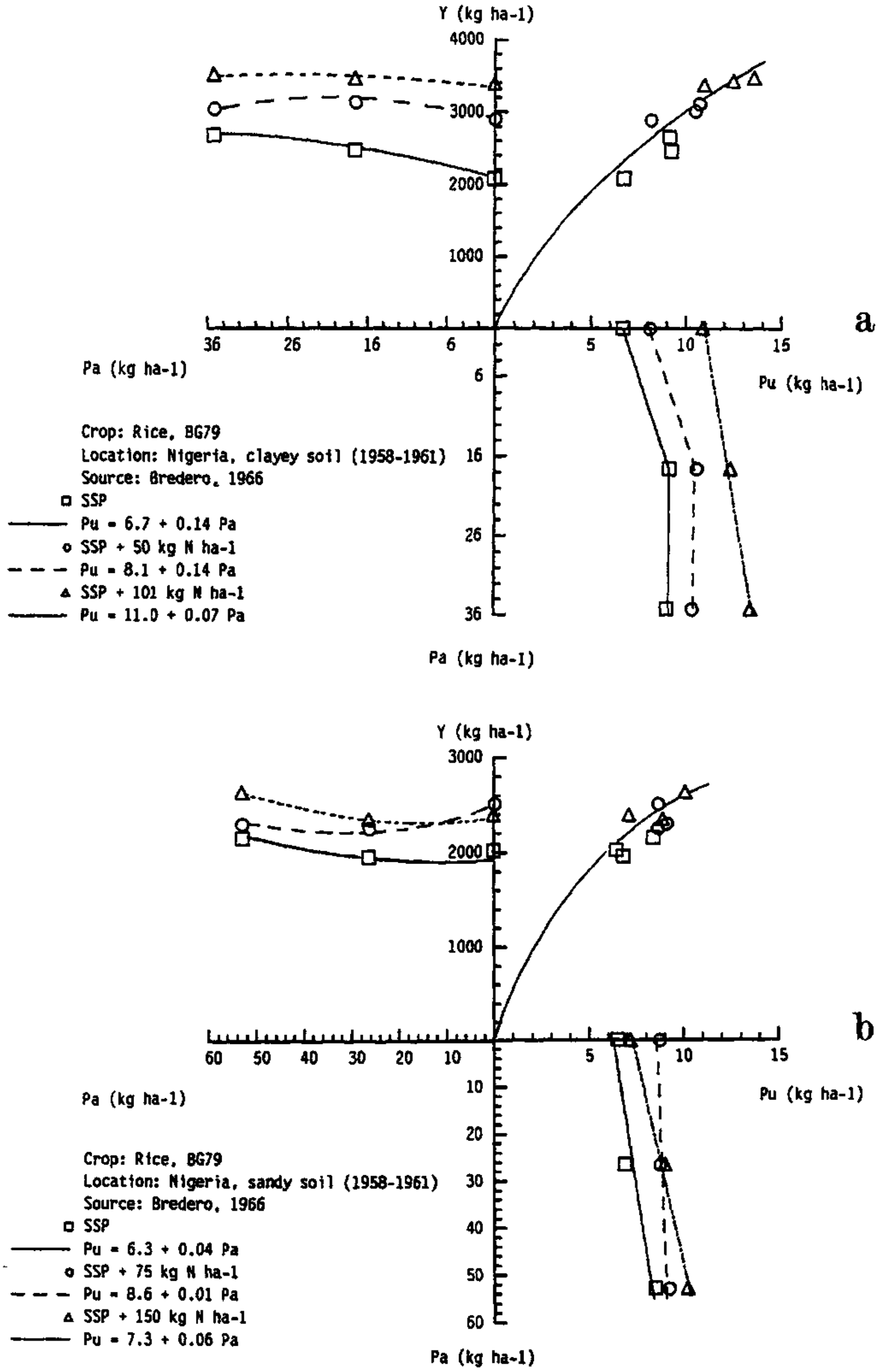
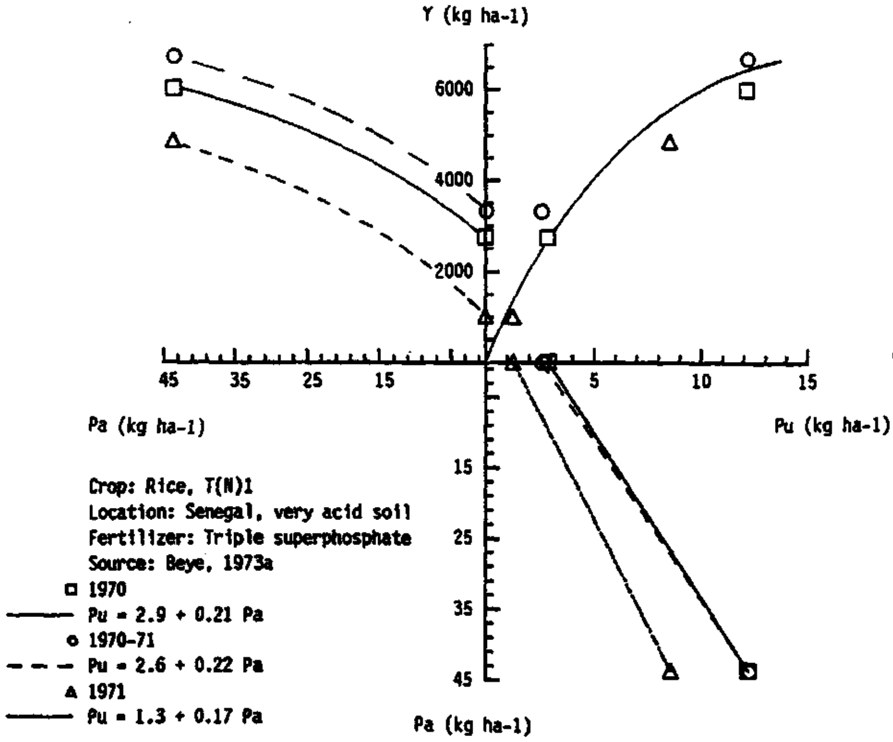
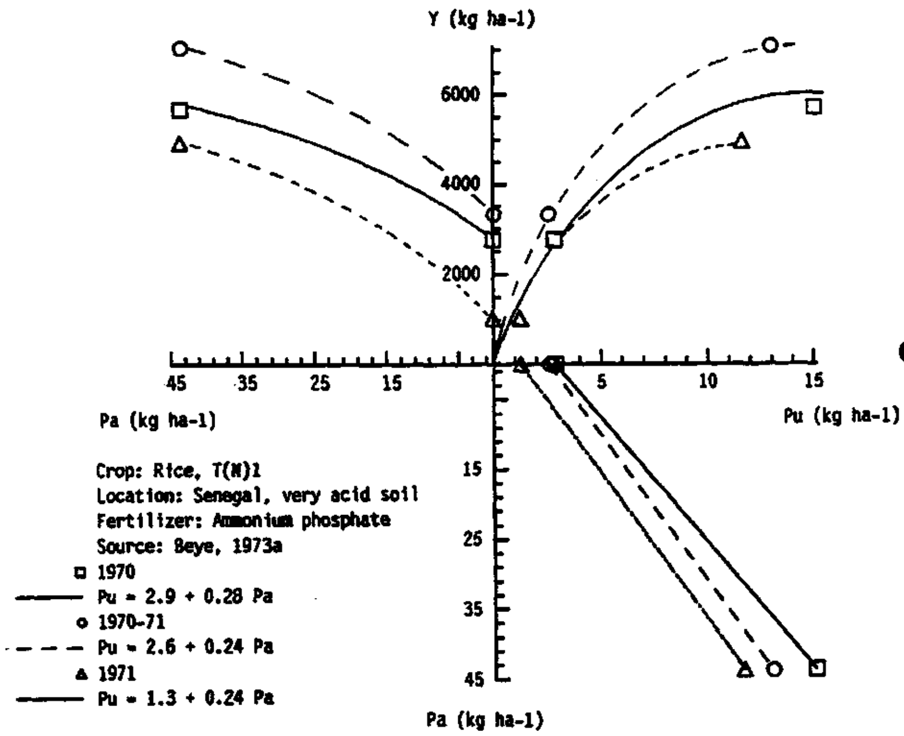


Figure 8.3. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield in rice.*

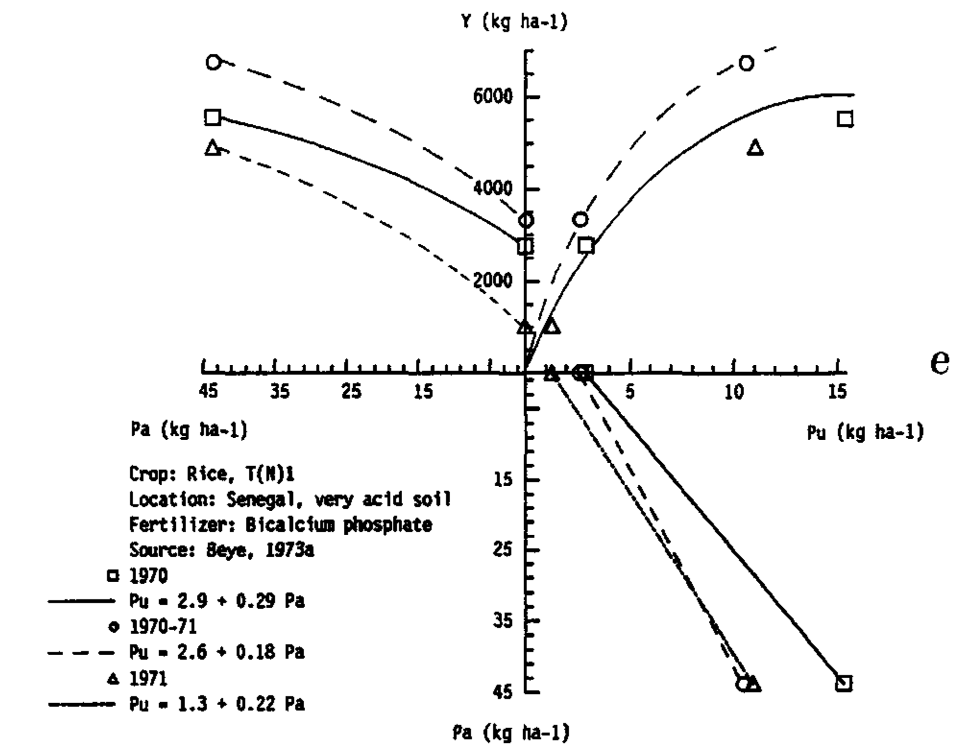


c



d

Figure 8.3. Continued.



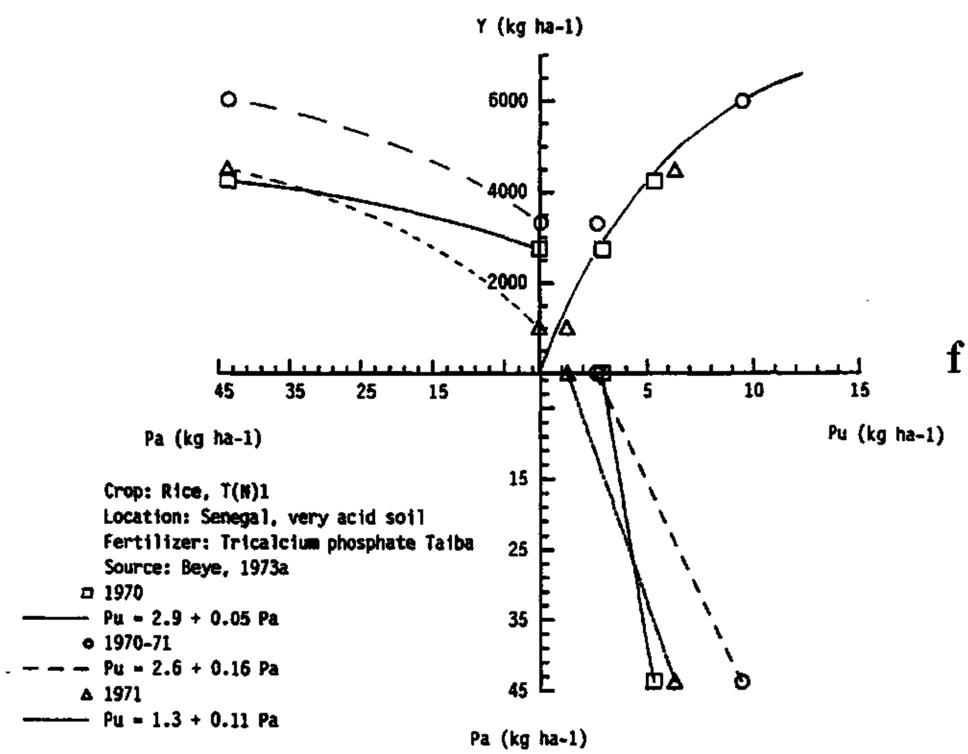
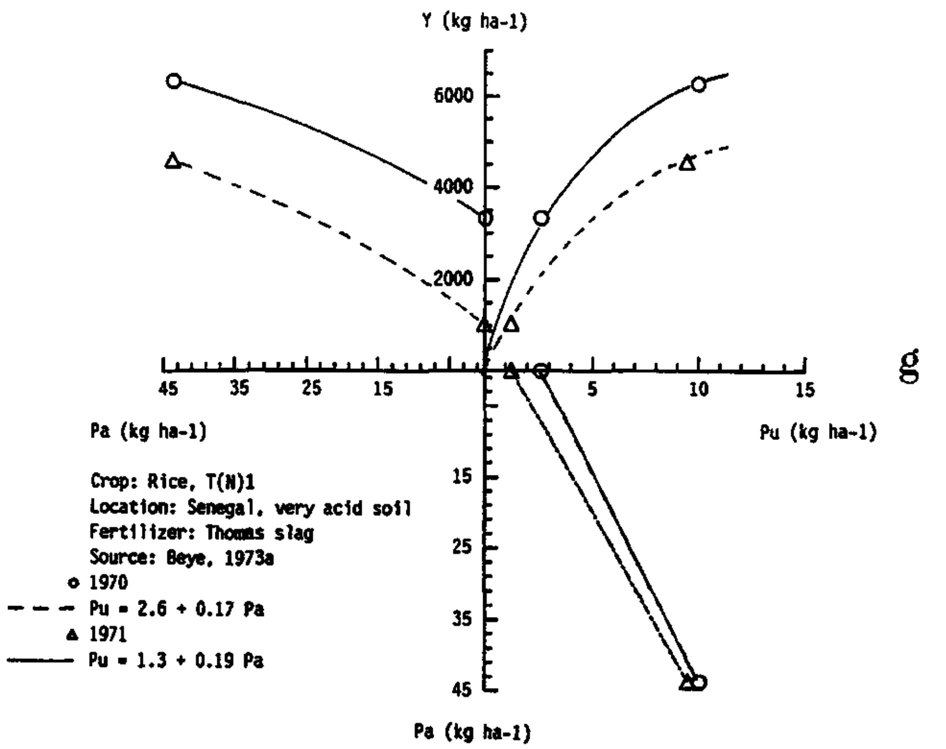


Figure 8.3. Continued.



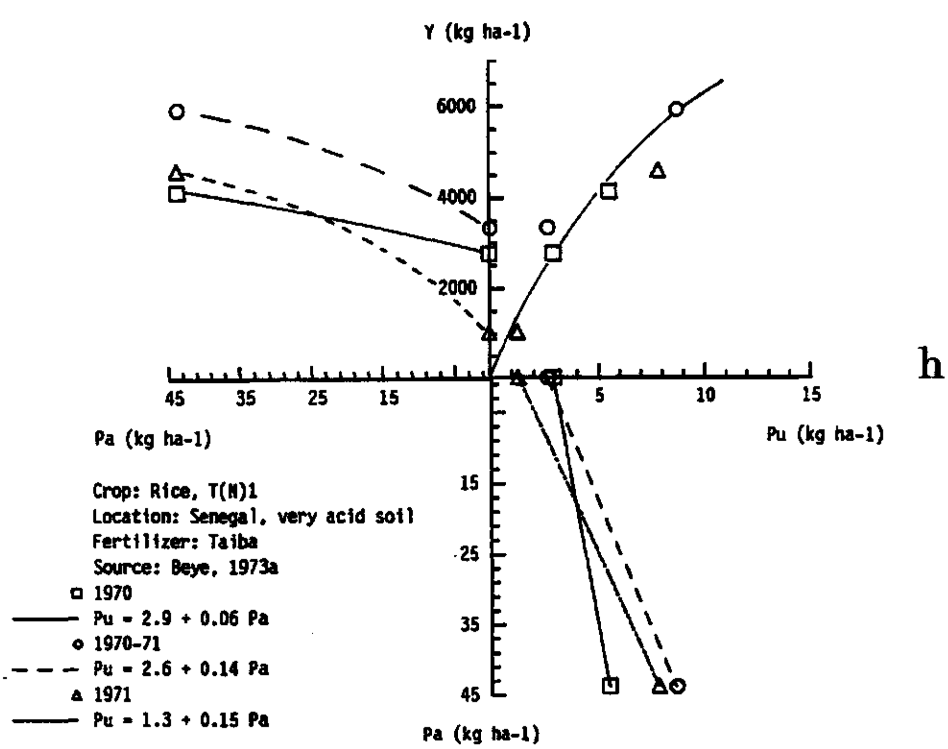


Figure 8.3. Continued.

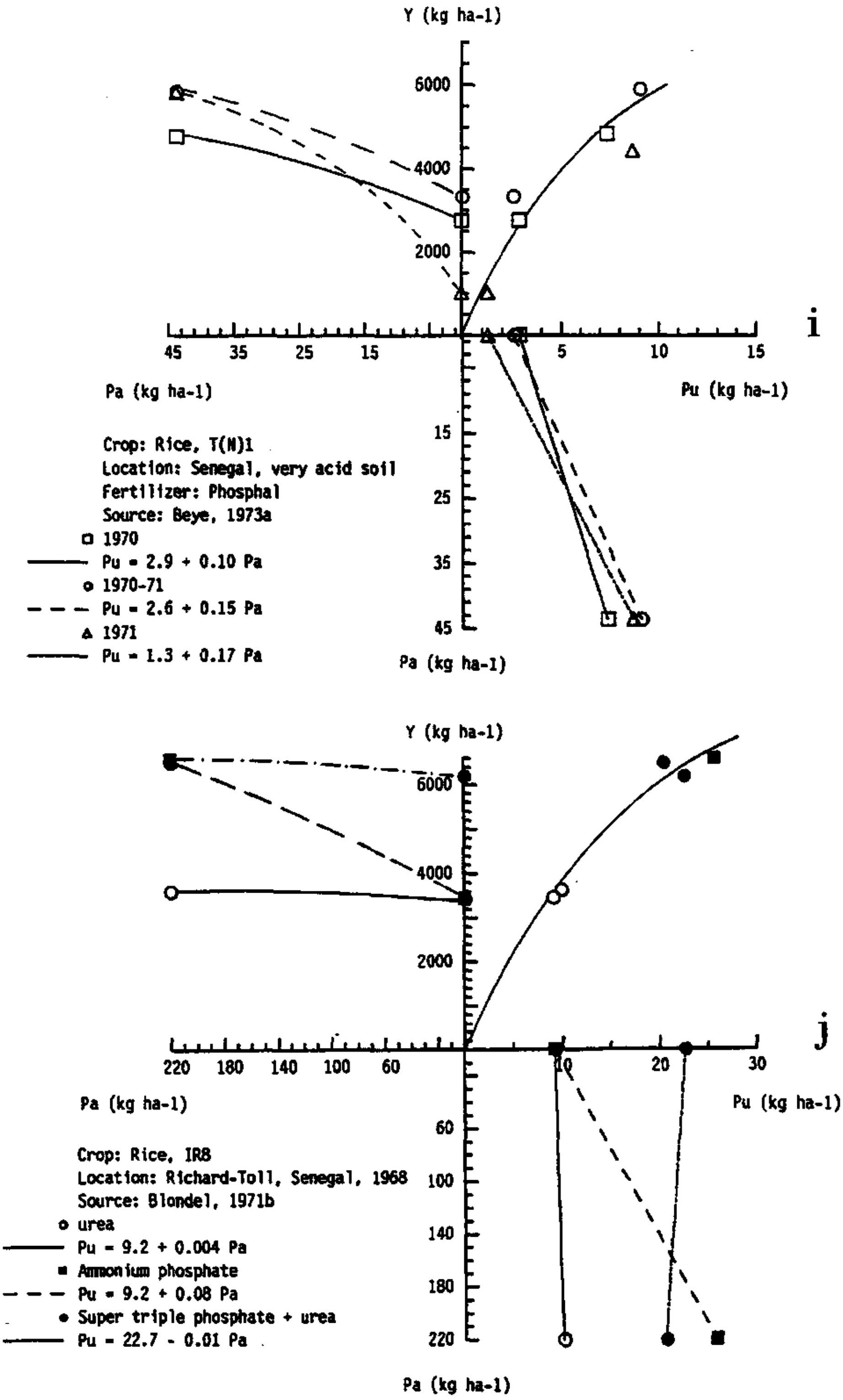


Figure 8.3. Continued.

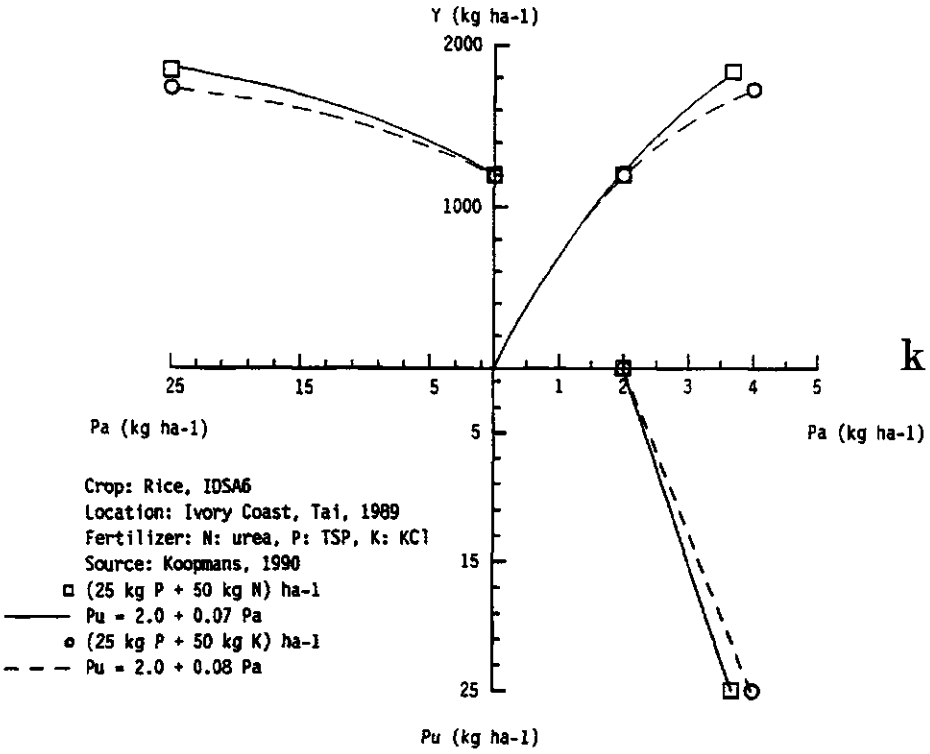


Figure 8.3. Continued.

8.3.3 Potassium

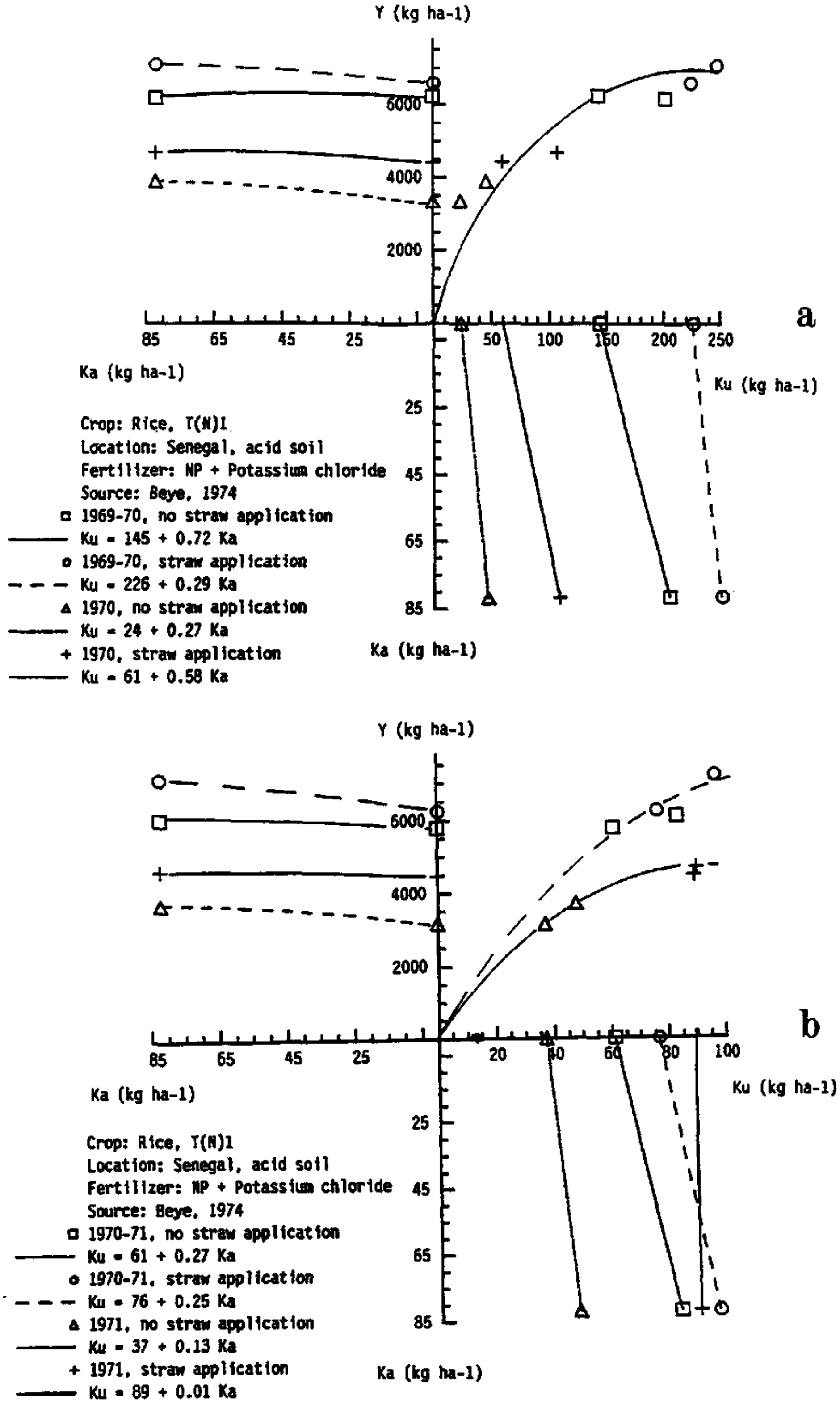


Figure 8.4. *Relation between total potassium content (K_u) and yield (Y), that between potassium application (K_a) and potassium content, and that between potassium application and yield in rice.*

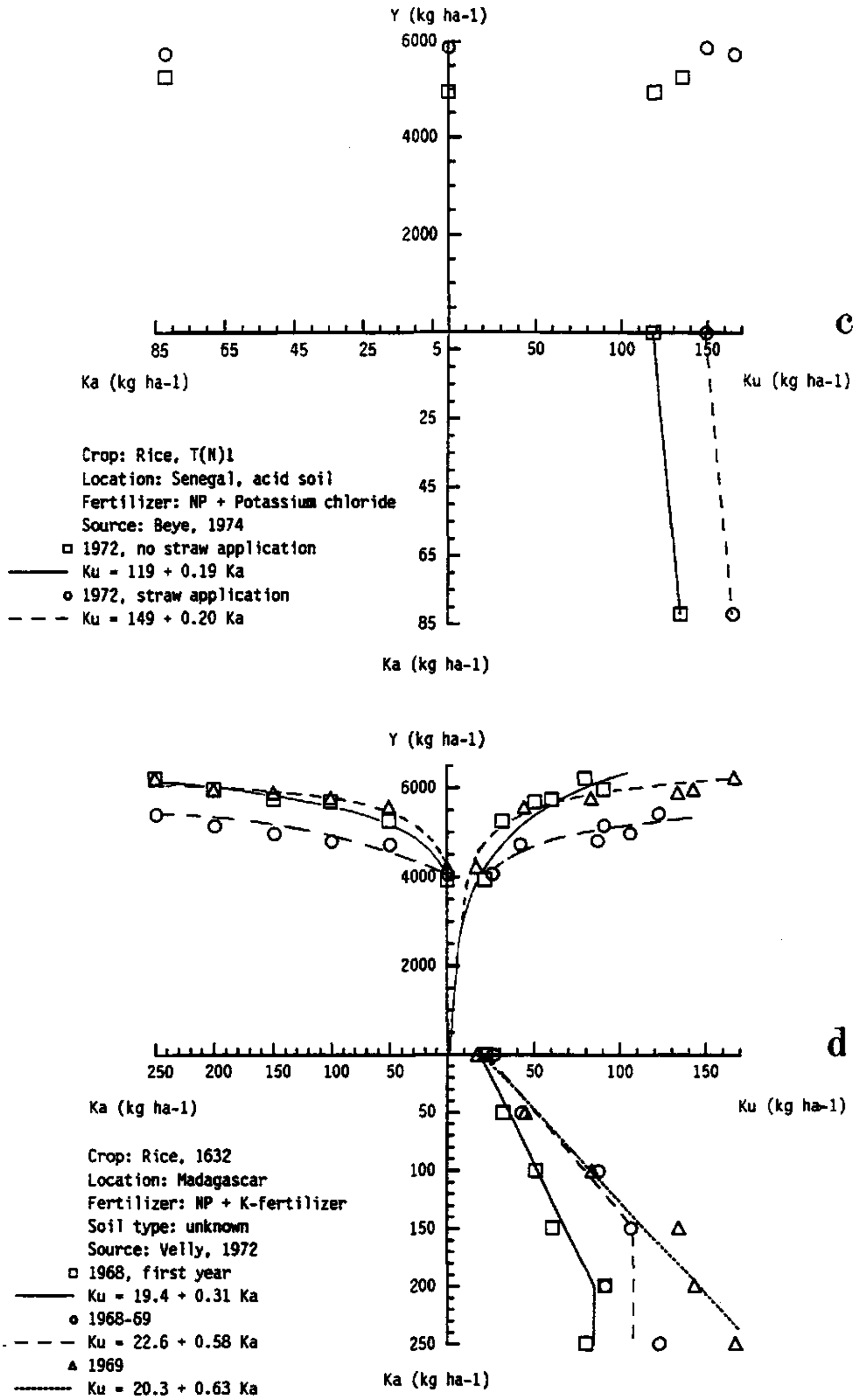


Figure 8.4. Continued.

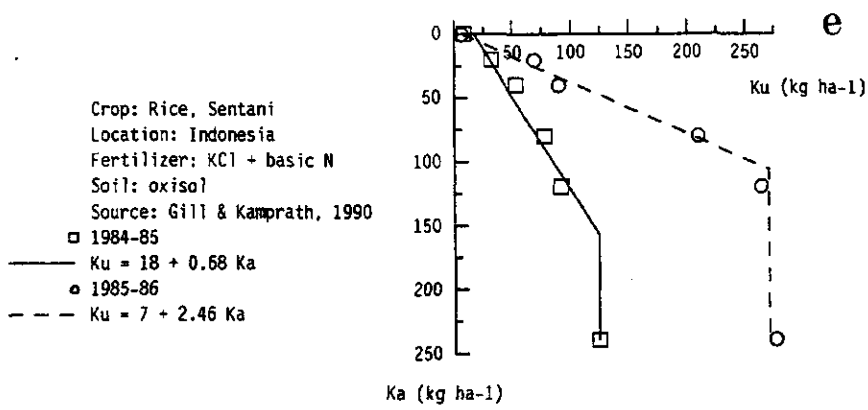


Figure 8.4. Continued.

8.4 Nutrient content as related to yield

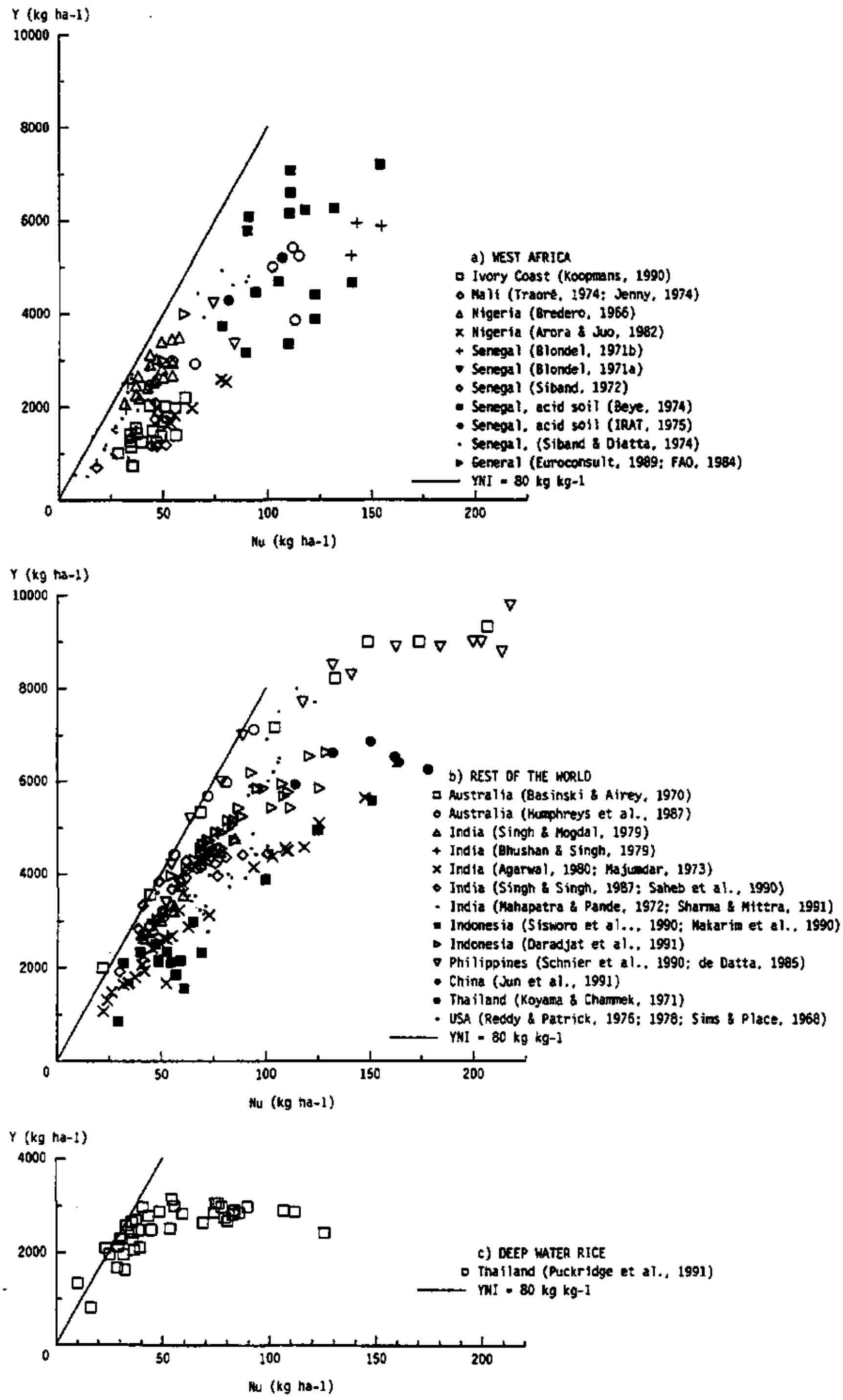


Figure 8.5. *Relation between total nitrogen content (N_u) and yield (Y) of lowland and upland rice, a) in West Africa, b) elsewhere and c) of deep water rice; YNI = initial slope.*

In the relationship yield/P-content, less phosphorus per unit grain produced has been taken up on acid soils than on a non acid soil (Figure 8.6), in constrast to the same relation for nitrogen (Figure 8.5).

Potassium is also further diluted in rice on acid soils than on other soil types (Figure 8.7).

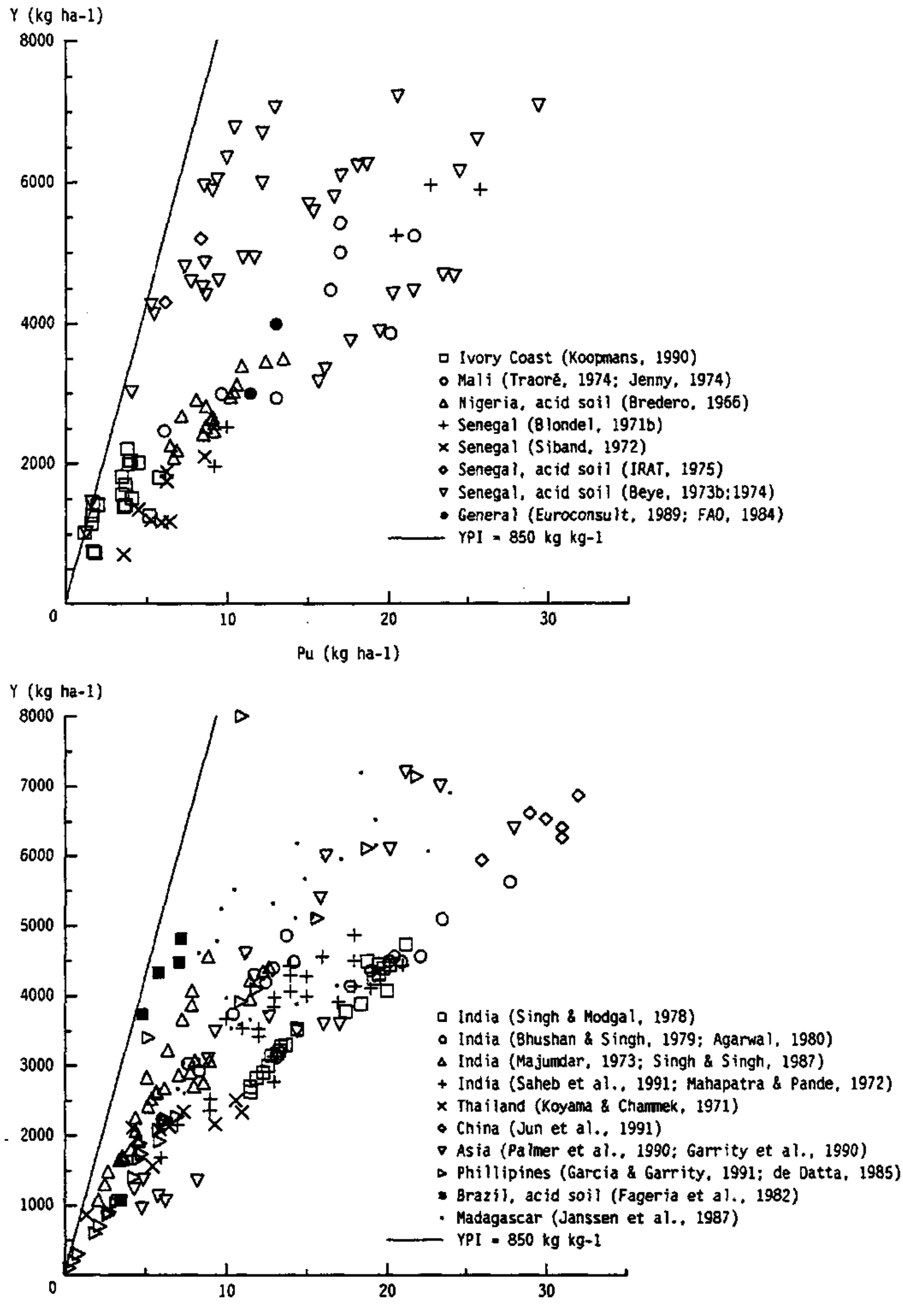
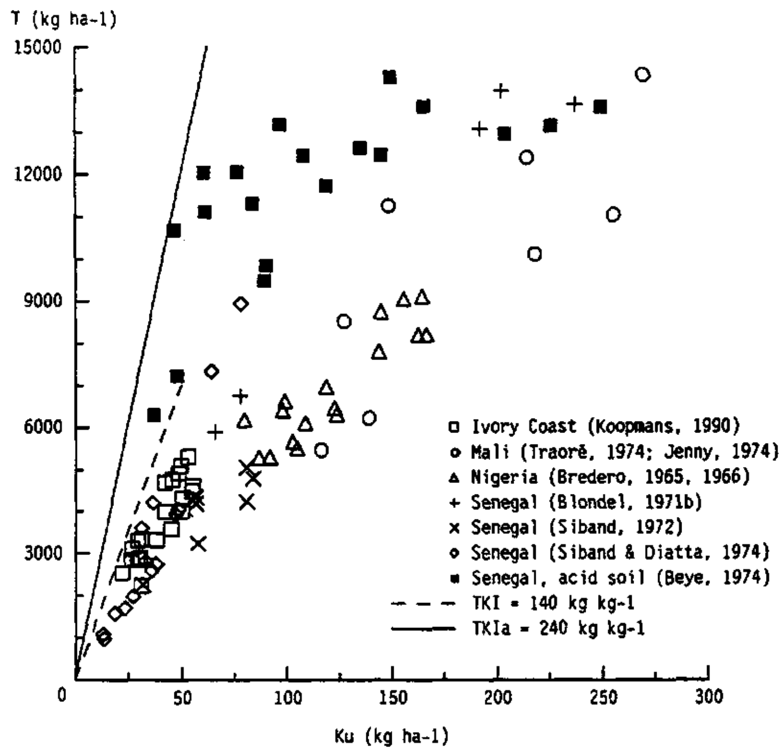


***Figure 8.6.** Relation between total phosphorus content (P_u) and yield (Y), a) in West Africa and b) elsewhere; YPI = initial slope.*



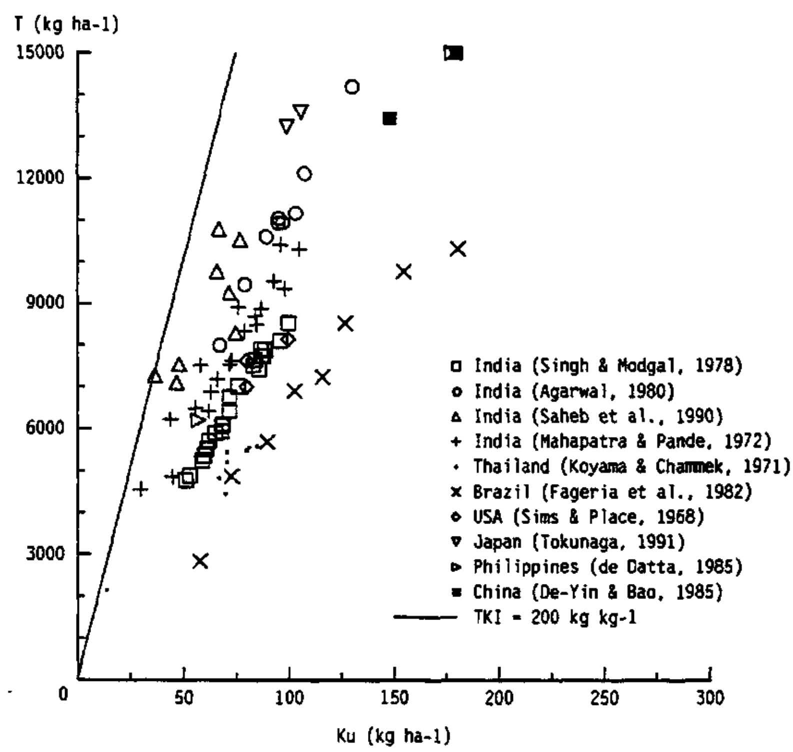


Figure 8.7. *Relation between total potassium content (K_u) and total aboveground dry matter (T) a) in West Africa and b) elsewhere: TKI = initial slope; TKIa = initial slope on acid soils.*

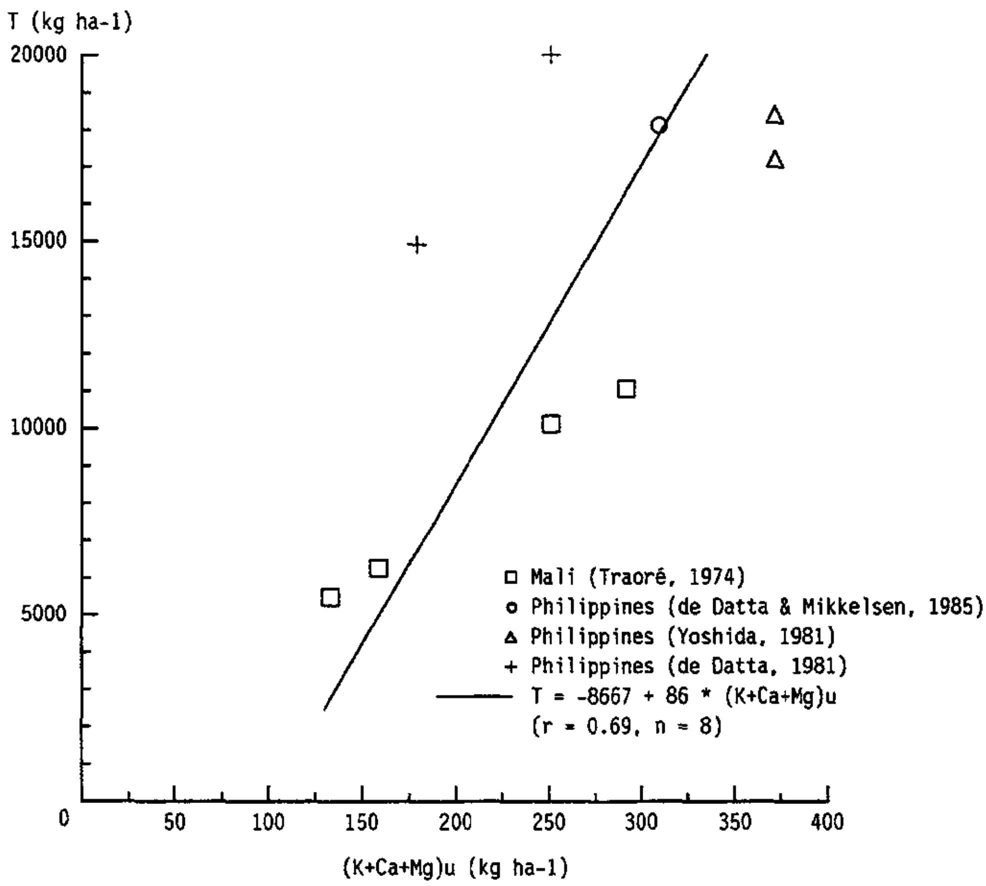


Figure 8.8. *Relation between the combined content of potassium, calcium and magnesium $(K+Ca+Mg)_u$ and total above-ground dry matter (T) in rice. Line represents average regression line.*

8.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 8.9; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

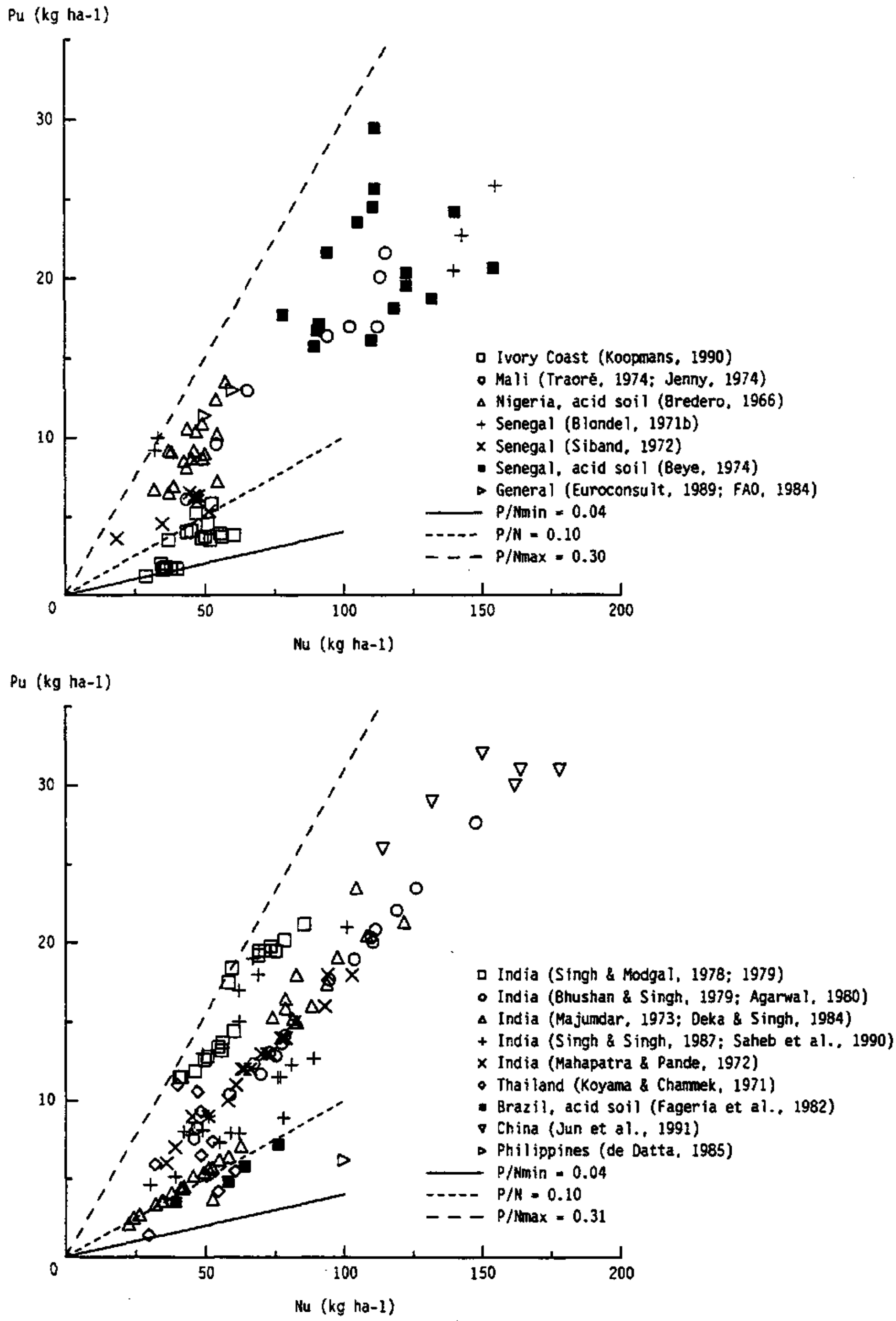


Figure 8.9. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of rice, a) in West Africa and b) elsewhere.*

8.6 Root nutrient content related to shoot nutrient content

The nitrogen and phosphorus content of roots is related to that of shoots, as illustrated in Figure 8.10. Unfortunately, such detailed data are scarce, hence, root nutrient content is calculated on an empirical basis in NUREQ.

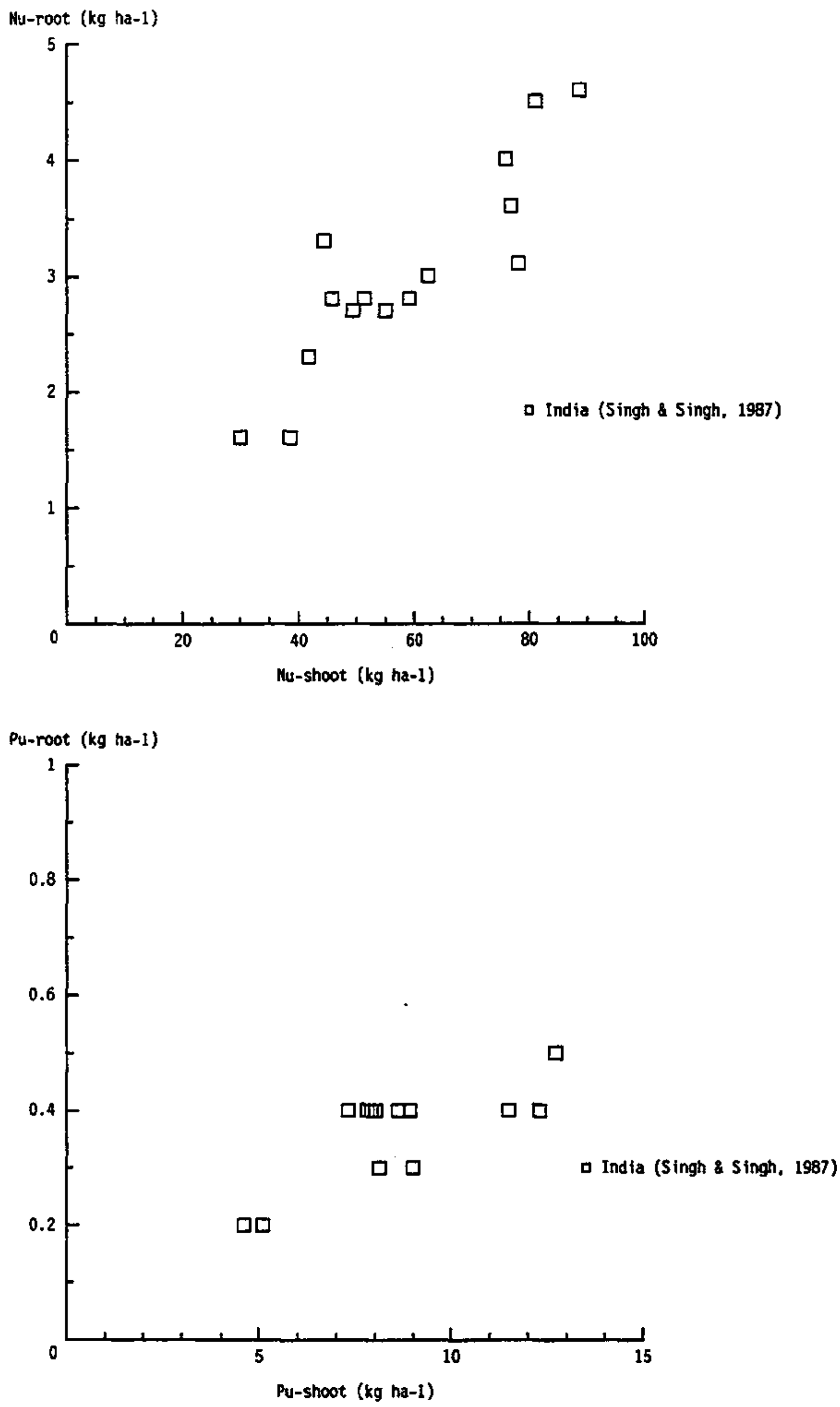


Figure 8.10. *Root nitrogen (a) and phosphorus (b) content as function of that of the shoot.*

8.7 Relations among relative post-anthesis nutrient uptake values of N, P and K

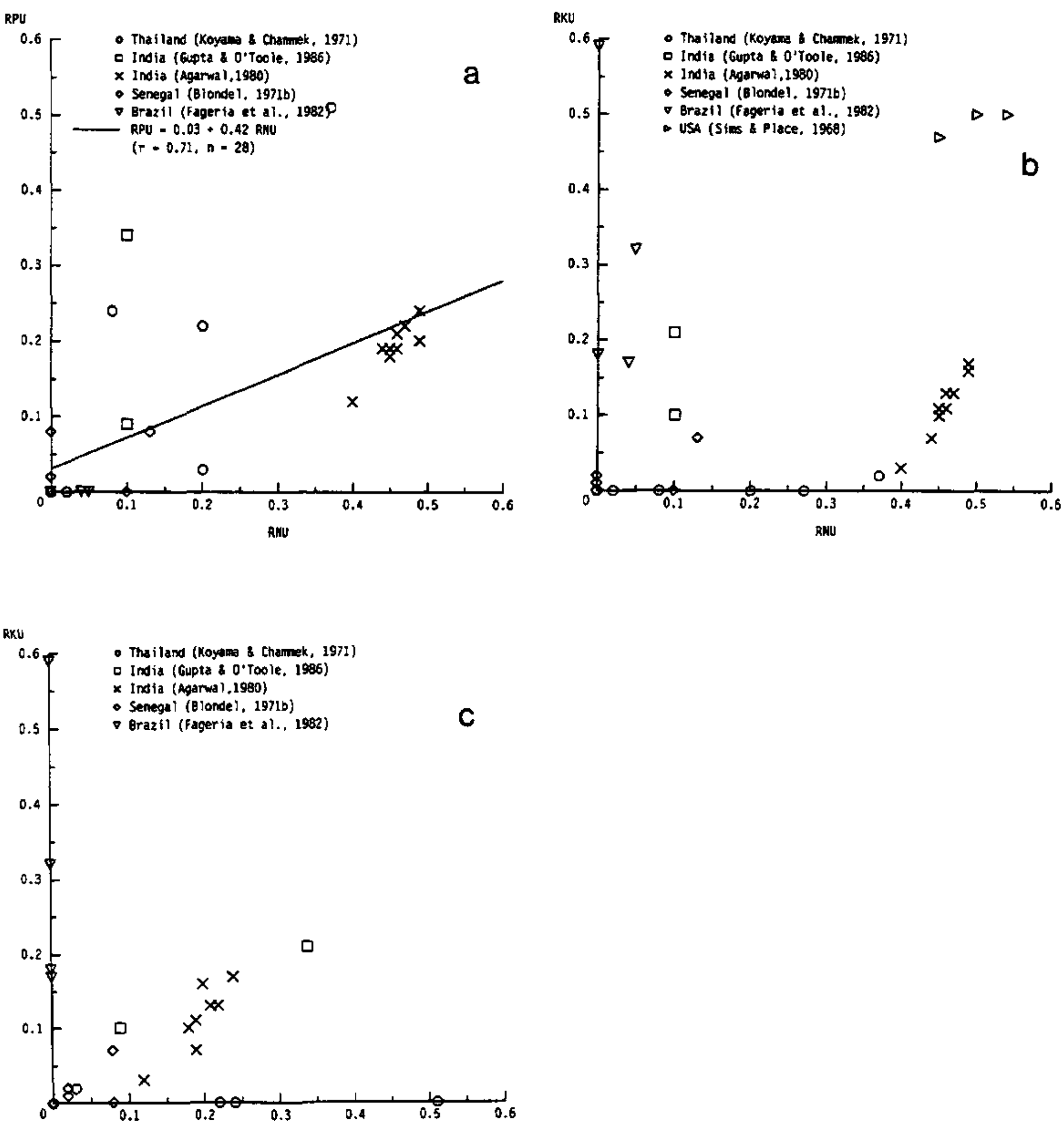


Figure 8.11. *Relationship between relative post-anthesis nutrient uptake in rice of a) nitrogen and phosphorus, b) nitrogen and potassium and c) phosphorus and potassium. Line represents average regression line.*

8.8 Nutrient harvest indices

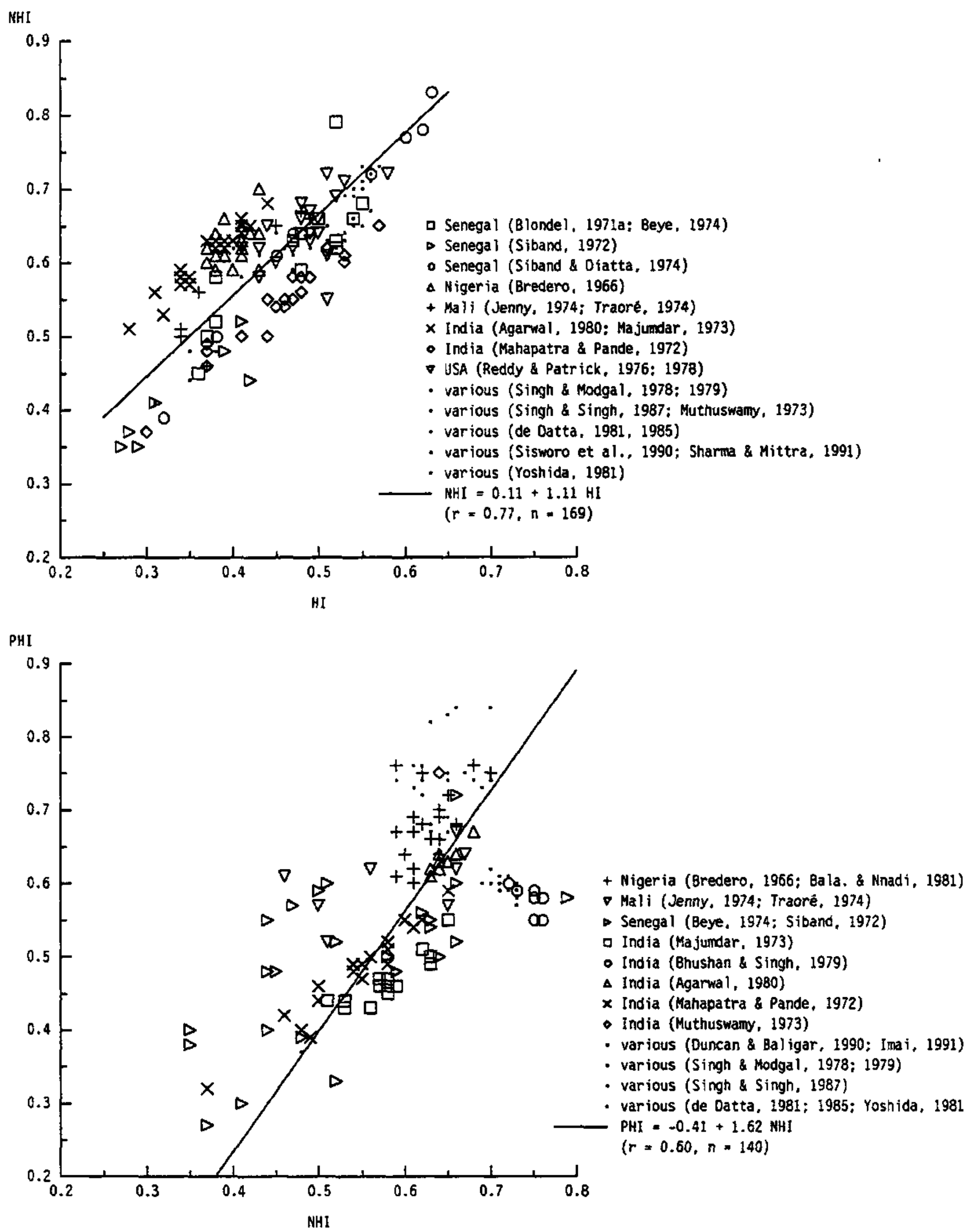


Figure 8.12. Relation between a) harvest index and nitrogen harvest index and b) nitrogen harvest index and phosphorus harvest index of rice. Line represents average regression line.

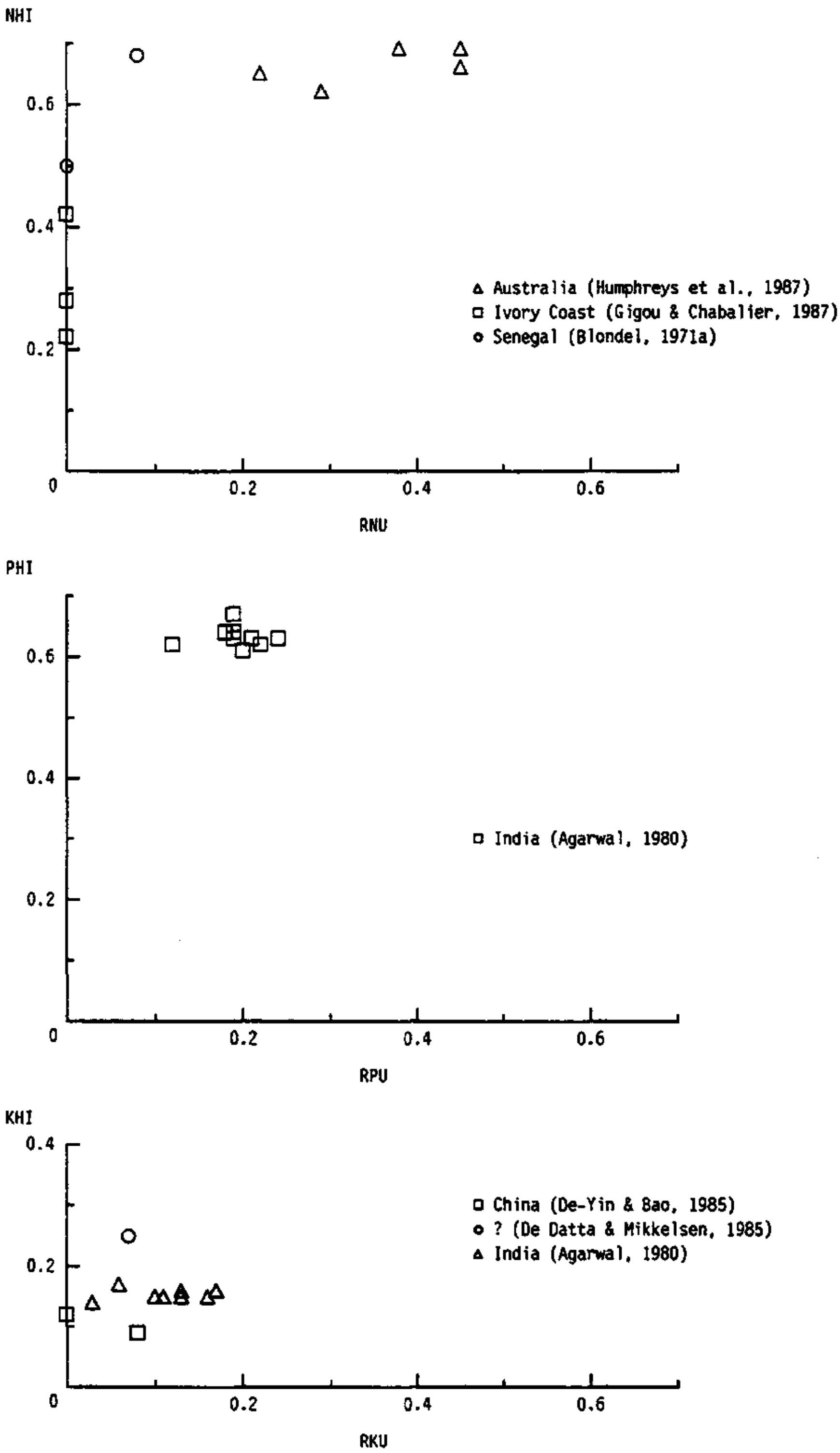


Figure 8.13. *Relation between relative post-anthesis nutrient uptake and nutrient harvest index in rice for a) nitrogen, b) phosphorus and c) potassium.*

9. WHEAT

Although wheat is not a major crop in West Africa, it is included for the purpose of comparison and its importance as a world-wide staple crop.

9.1 Dry matter distribution

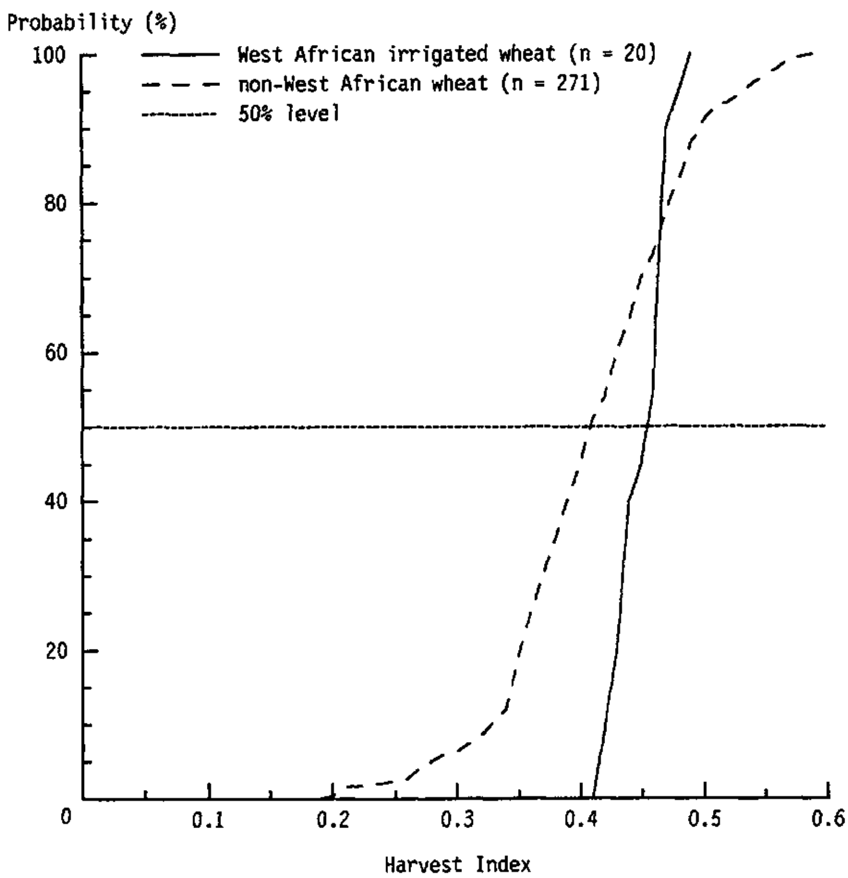


Figure 9.1. *Harvest index distribution of wheat under different conditions.*

Sources West Africa: Balasubramanian & Singh, 1982;

Elsewhere: Atanasiu et al., 1978b; Bishop & McEachern, 1971; Boatwright & Haas, 1961; Cox et al., 1985; Eilrich & Hageman, 1973; Ellen & Spiertz, 1975, 1980; Groot, 1987; Hamid, 1973; Hamid & Sarwar, 1977; Khetawat et al., 1972; Lal et al., 1978; Maliwal, 1990; McNeal et al., 1966; Orphanos & Krentos, 1980; Paccaud et al., 1985; Prasad et al., 1985; Racz et al., 1965; Singh et al., 1980; Spiertz & Ellen, 1978; Spiertz & Vos, 1983; Talati et al., 1974; Thorne et al., 1988; Verstraeten & Livens, 1975; Woodruff, 1972;

Not included here, but for analysis of HI (Table 2.4) additionally used: Black et al., 1946; Lal & Sharma, 1974; Ralph & Ridgman, 1981; Papakosta & Gagianas, 1991; Wuest & Cassman, 1992b.

9.2 Concentration of major elements

Table 9.1. *Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total aboveground biomass of wheat at maturity; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
Nigeria	irrigation			22.8	25.1			Singh & Balasu-bramanian, 1983
	irrigated			16.2	17.4			Balasubramanian &
				16.5	19.2			Singh, 1982
			6.2					Balasubramanian & Nnadi, 1981
Argentina				20.9	23.3			Echeverria *ea*, 1992
Australia				21.9	26.7			Woodruff, 1972
Belgium		2.4	3.6	15.3	20.7			Verstraeten & Livens, 1975
Canada		2.2	4.6	19.2	29.5			Bishop & MacEachern, 1971
Cyprus				19.9	24.5			Orphanos &
				16.7	19.3			Krentos, 1980
				24.8	31.7			Orphanos &
				21.3	27.2			Krentos, 1980
		3.4	6.0	23.3	31.7			Orphanos &
		3.8	6.4	20.7	27.1			Krentos, 1980
		4.0	6.0	25.9	35.3			Orphanos &
		4.0	6.2	22.5	31.8			Krentos, 1980
Great Britain		3.2	5.2	17.0	22.4			Thorne *ea*, 1988
		6.1	17.8	17.6	18.9			Gasser & Thorn-
		5.3	16.7	14.8	19.8			burn, 1972
						8.6		Page *ea*, 1977
		2.7	7.2	13.7	24.4			Dyke *ea*, 1982
			6.3		18.5			Barraclough, 1986
India		4.2	5.3	16.9	21.5			Khetawat *ea*, 1972
		2.4		19.6			10.3	Ahlawat *ea*, 1981
		3.9	8.4	15.8	22.2			Lal & Sharma,1974
		4.6	8.5	16.5	22.1			Lal & Sharma,1974
				15.0	21.4			Singh *ea*, 1974
Netherlands		3.4	5.4	12.9	19.1			Ellen & Spiertz, 1980
		3.9	5.0	17.3	23.8	9.4	13.9	Spiertz & Ellen, 1978
USA		4.1	5.6	22.7	28.0			Eilrich & Hageman 1973
		7	13	26	30			Racz *ea*, 1965

.../...

Table 9.1. Continued.

COUNTRY	REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen								
	Rojo	2.7	6.2	18.9	28.5			Cassman *ea*, 1992
	Anaa	2.3	6.6	15.0	21.7			Cassman *ea*, 1992
Phosphorus								
Nigeria	irrigation			4.5	5.3			Singh & Balasu-bramanian, 1983
			1.2					Balasubramanian & Nnadi, 1981
Canada		0.3	0.6	3.9	4.4			Bishop & MacEachern, 1971
Cyprus				3.8	4.0			Orphanos &
				3.0	3.3			Krentos, 1980
				3.6	4.1			Orphanos &
				2.9	3.4			Krentos, 1980
Cyprus				3.1	3.3			Orphanos &
				2.8	2.9			Krentos, 1980
Great Britain		0.4	0.8	3.4	4.1	1.6	2.3	Thorne *ea*, 1988
		1.4	2.6	3.2	3.3			Gasser & Thorn-
		1.5	2.7	3.2	3.7			burn, 1972
						1.8		Page *ea*, 1977
		0.3	1.6	1.8	4.3			Dyke *ea*, 1982
			1.3		3.5			Barraclough, 1986
India		0.2	1.0	3.6	5.1	1.3	2.4	Khetawat *ea*, 1972
		0.5	0.8	3.5	3.7	1.6	1.8	Lal & Sharma, 1974
		0.6	0.8	3.6	3.8	1.7	2.0	Lal & Sharma, 1974
						1.7	2.1	Singh, 1962
						1.3	2.8	Singh *ea*, 1971
						2.1	2.3	Singh *ea*, 1971
				2.1	2.4			Singh *ea*, 1974
Netherlands		0.2	0.3	3.7	4.3	1.8	1.9	Spiertz & Ellen, 1978
Pakistan		0.3	0.4	2.3	2.8	1.0	1.2	Hamid & Sarwar, 1977
USA		0.7	1.4	3.8	5.2	1.5	2.1	Racz *ea*, 1965
Potassium								
Nigeria	irrigation			6.3	6.9			Singh & Balasu-bramanian, 1983
			17.2					Balasubramanian & Nnadi, 1981
Canada		12.2	22.4	4.4	4.9			Bishop & MacEachern, 1971
Cyprus		9.2	11.9			8.4	10.0	Orphanos &
		11.8	14.7			8.9	12.5	Krentos, 1980
		6.9	8.6			6.2	7.7	Orphanos &
		11.1	13.1			9.0	11.3	Krentos, 1980

.../...

Table 9.1. Continued.

COUNTRY	REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Potassium								
Great Britain		10.7	19.0	4.5	4.6	8.1	12.8	Thorne *ea*, 1988
		8.0	12.0	4.3	4.6			Ralph & Ridgman,
		8.5	11.6	4.4	4.6			1981
		8.3	12.9	4.3	4.7			Ralph & Ridgman,
		13.8	17.4	4.1	5.2			1981
		11.5	15.0	4.1	4.8			Ralph & Ridgman,
		8.2	12.3					1981
		8.0	11.2					Ralph & Ridgman,
		8.5	10.8					1981
		13.5	23.8	8.6	11.2			Gasser & Thorn-
		14.8	26.1	8.1	12.0			burn, 1972
						7.0		Page *ea*, 1977
		1.8	23.5	3.1	5.6			Dyke *ea*, 1982
			16.2		5.4			Barraclough, 1986
		5.1	11.8	4.8	5.3			Chambers, 1953a
India		12.0	18.6	4.3	4.7	10.3	13.9	Khetawat *ea*, 1972
		15.0	17.7	6.7	6.9	12.0	14.0	Lal & Sharma,1974
		18.3	21.1	6.7	7.5	14.1	16.3	Lal & Sharma,1974
		16.3	17.7	3.2	3.8	16.3	17.7	Talati *ea*, 1974
				4.0	4.3			Singh *ea*, 1974
Netherlands		8.5	15.5	3.1	3.5	6.5	9.8	Spiertz & Ellen, 1978
Calcium								
Great Britain		3.6	3.9	0.7	1.3			Gasser & Thorn-
		3.1	3.4	0.6	1.1			burn, 1972
			3.3	0.4				Barraclough, 1986
		2.1	3.1	0.4	0.5			Chambers, 1953a
Nigeria		2.7						Balasubramanian & Nnadi, 1981
Magnesium								
Great Britain		0.4	0.5	1.0	1.1			Ralph & Ridgman,
		0.4	0.5	0.9	1.0			1981
		0.5	0.6	1.0	1.1			Ralph & Ridgman,
		0.4	0.6	1.0	1.2			1981
		0.4	0.6	1.0	1.1			Ralph & Ridgman, 1981
		0.4	0.8	0.9	1.0			Gasser & Thorn-
		0.4	0.7	0.9	1.1			burn, 1972
		0.2	0.8	0.5	1.3			Dyke *ea*, 1982
			0.8		0.9			Barraclough, 1986
		0.5	0.6	1.1	1.3			Chambers, 1953a
Nigeria			1.5					Balasubramanian & Nnadi, 1981

.../...

Table 9.1. *Continued.*

COUNTRY	REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Sulfur								
Nigeria			1.2					Balasubramanian & Nnadi, 1981
Sodium								
Great Britain		0.1	0.2		0.1			Gasser & Thorn-
		0.2	0.2		0.1			burn, 1972

9.3 Three quandrant figures

9.3.1 Nitrogen

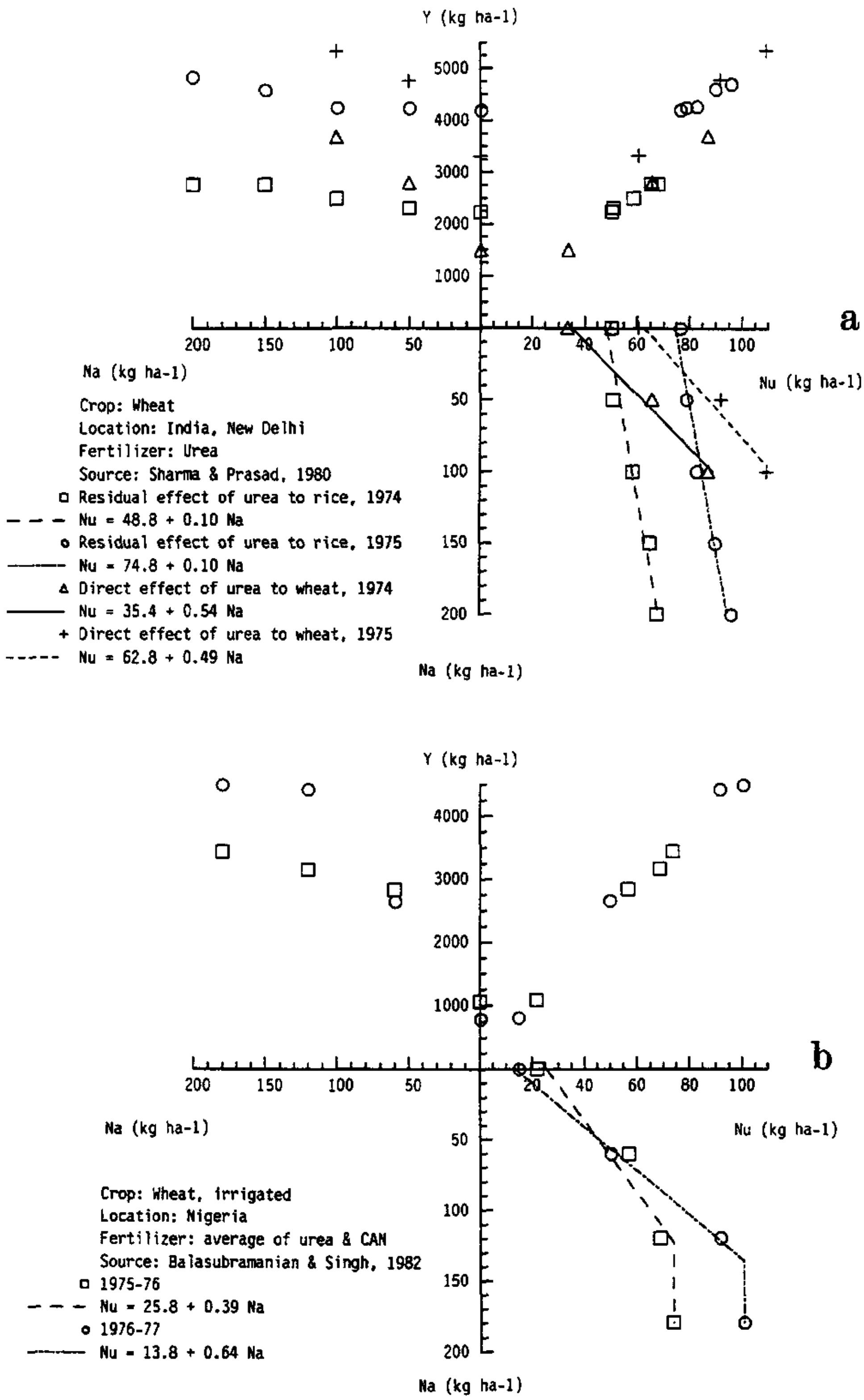


Figure 9.2. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield in wheat.*

9.3.2 Phosphorus

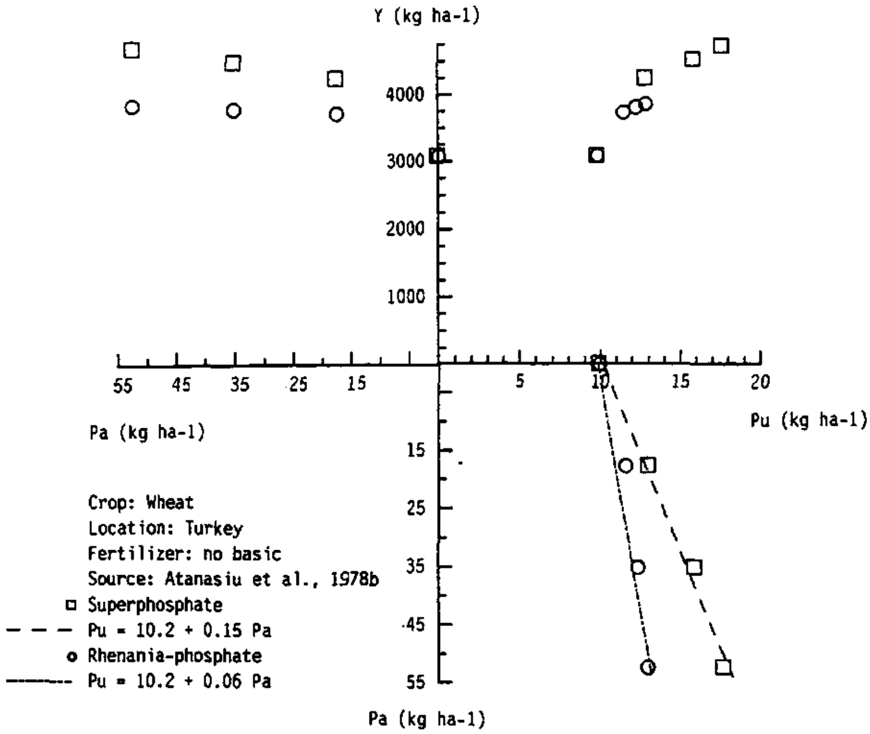


Figure 9.3. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield in wheat.*

9.3.3 Potassium

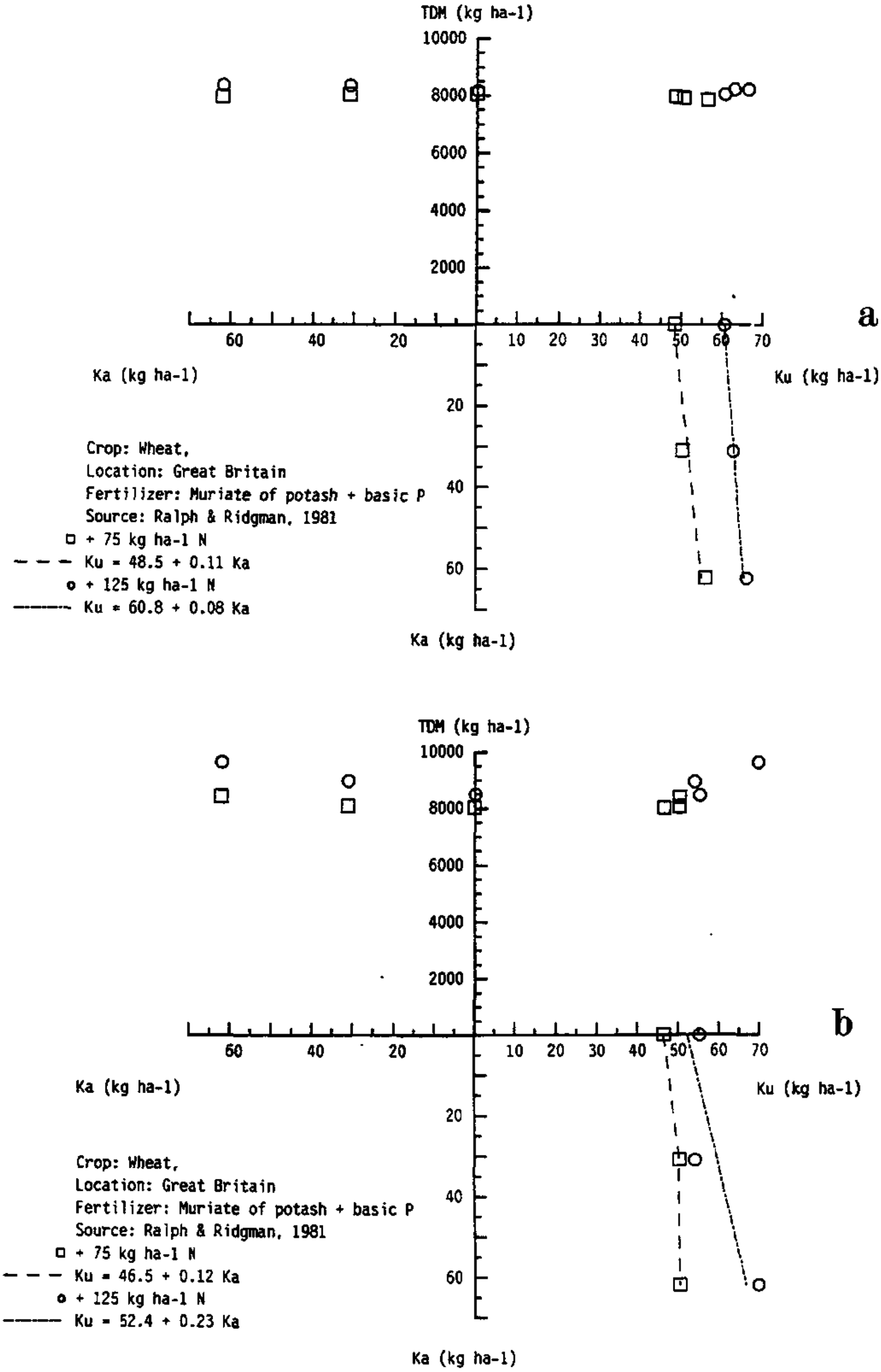


***Figure 9.4.** Relation between total potassium content (K_u) and yield (Y), that between potassium application (K_a) and potassium content, and that between potassium application and yield in rice.*

9.4 Nutrient content as related to yield

In the relation yield/N-content, no lacations differences occur (Figure 9.5), but in the one for phosphorus (Figure 9.6), differences are obvious. However, for West African conditions only limited information was available. for the relation toal aboveground biomass/K-content, only data outside West Africa were available (Figure 9.7).

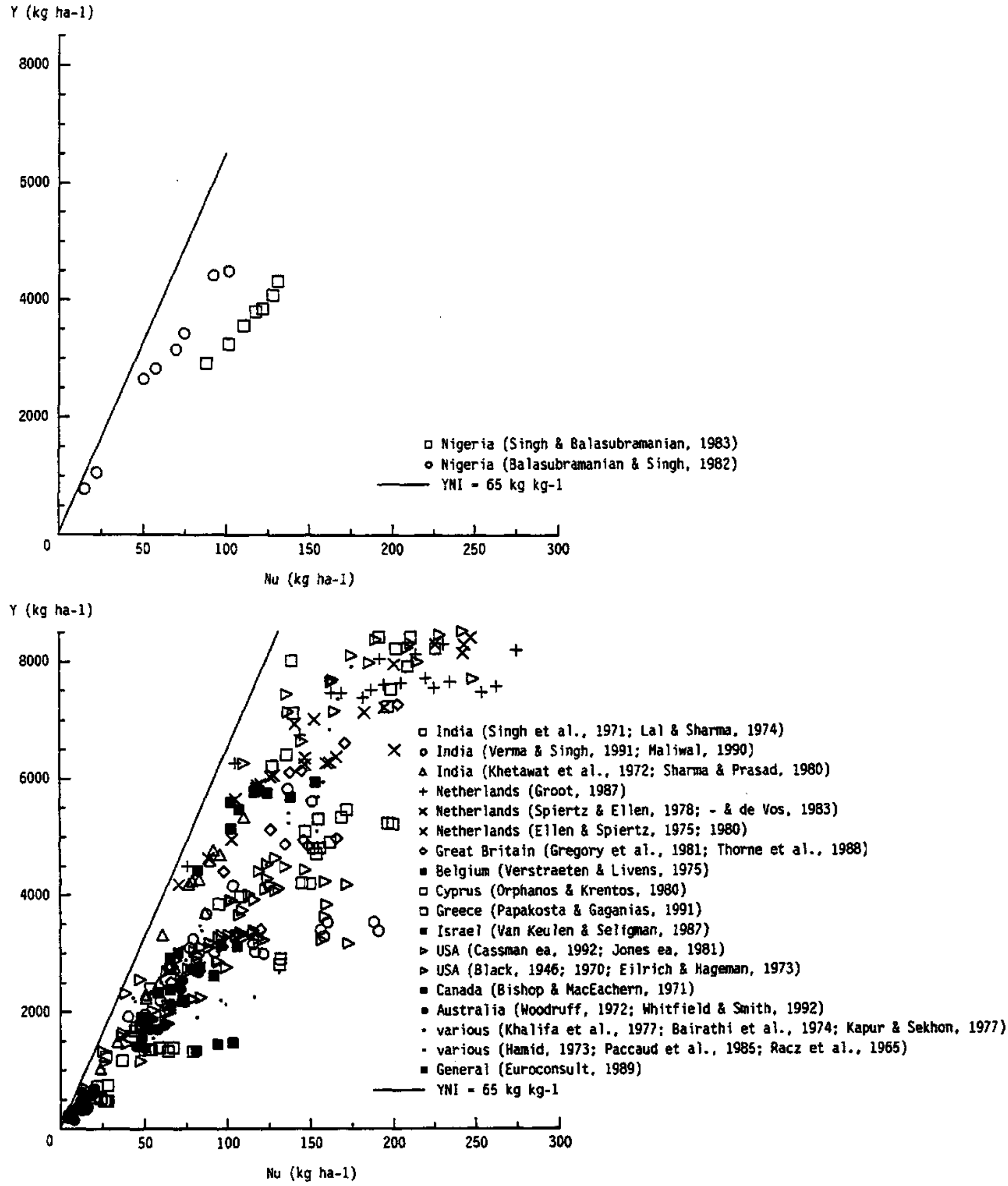
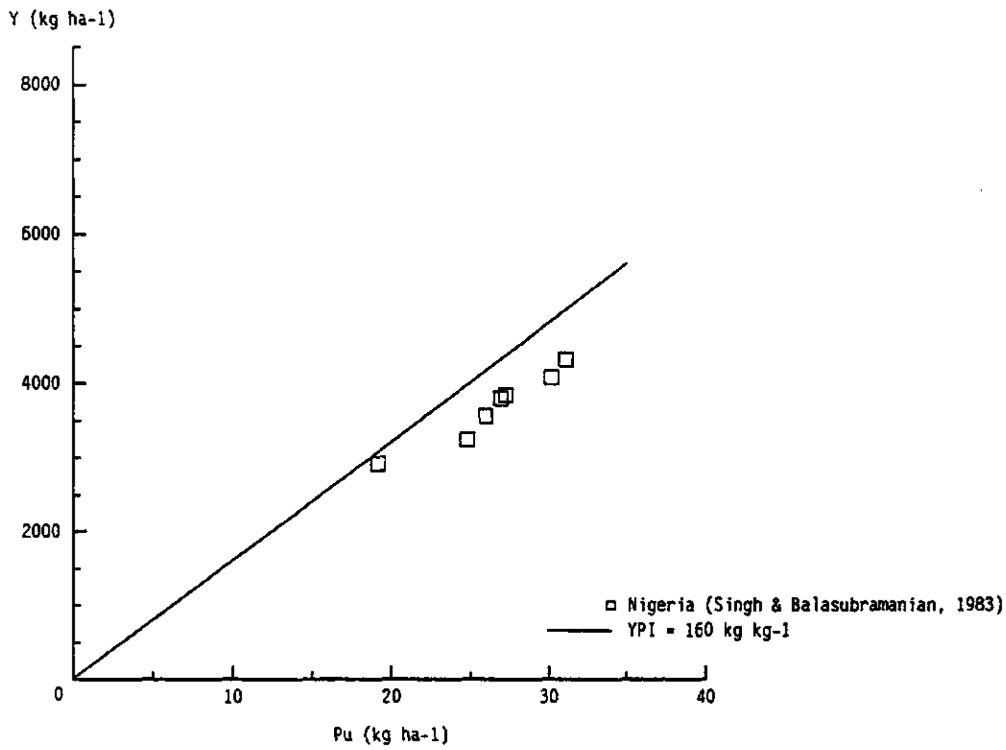


Figure 9.5. *Relation between total nitrogen content (N_u) and yield (Y), a) in West Africa and b) elsewhere; YNI = initial slope.*



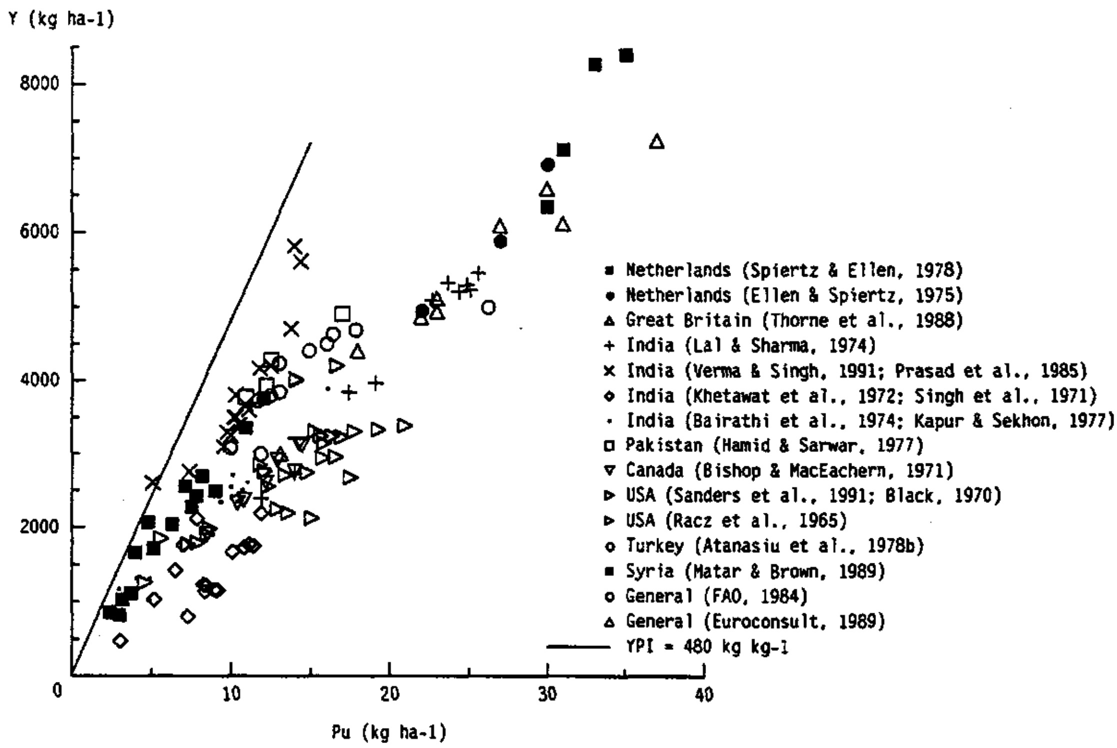


Figure 9.6. *Relation between total phosphorus content (P_u) and yield (Y), a) in West Africa and b) elsewhere; YPI = initial slope.*

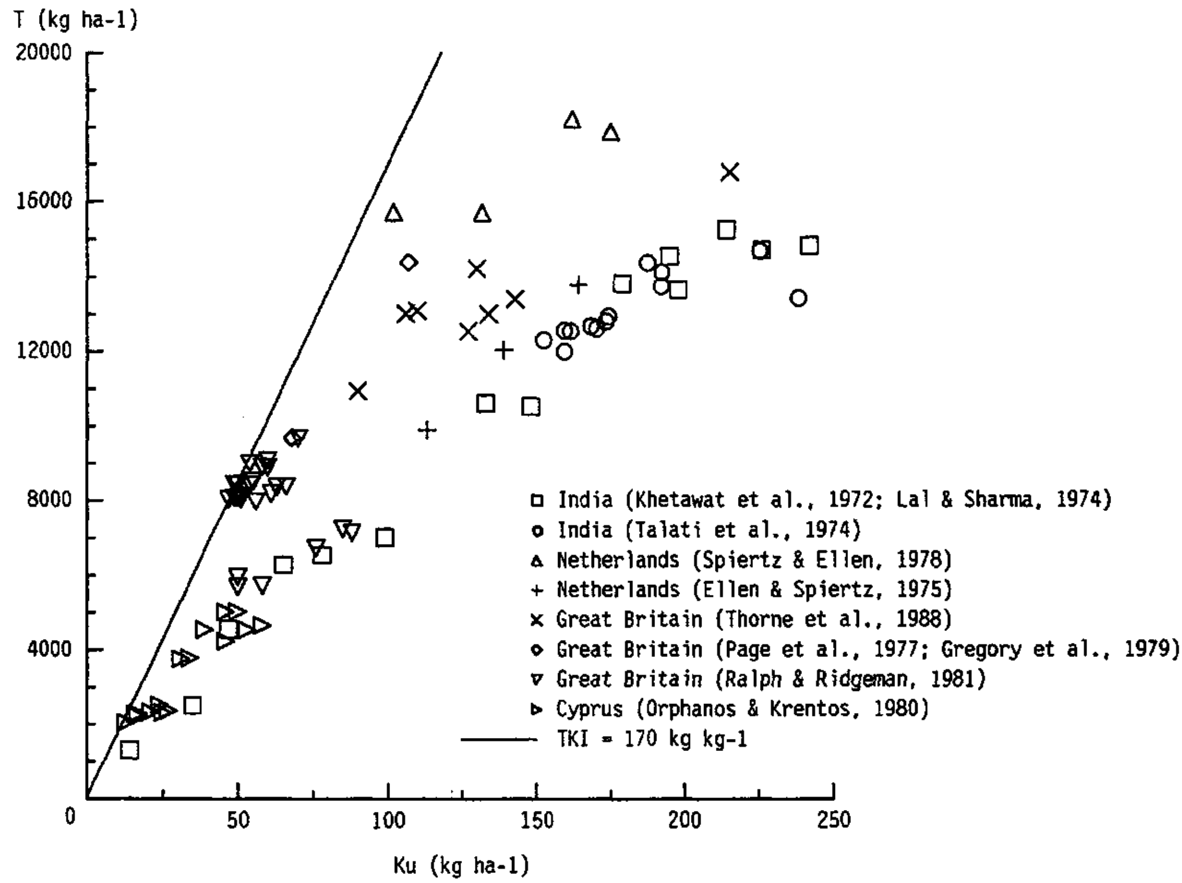


Figure 9.7. *Relation between total potassium content (K_u) and total aboveground dry matter (T) outside West Africa; TKI = initial slope.*

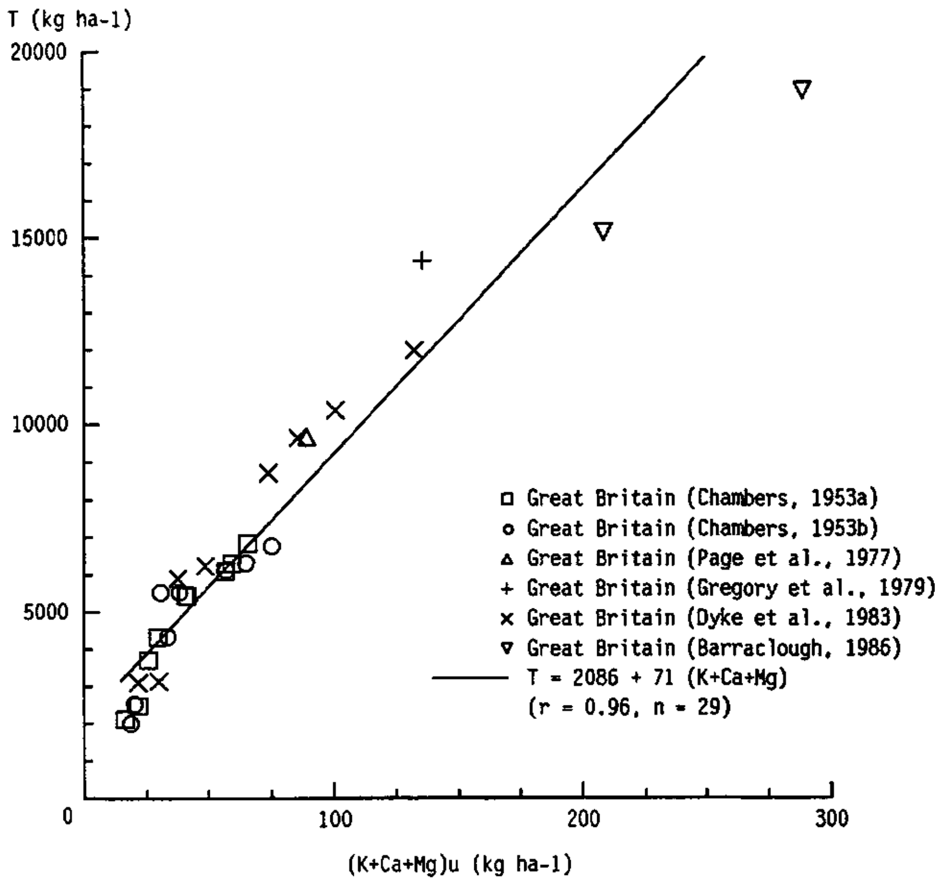


Figure 9.8. *Relation between the combined content of potassium, calcium and magnesium $(K+Ca+Mg)_u$ and total above-ground dry matter (T) in wheat. Line represents average regression line.*

9.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 9.9; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

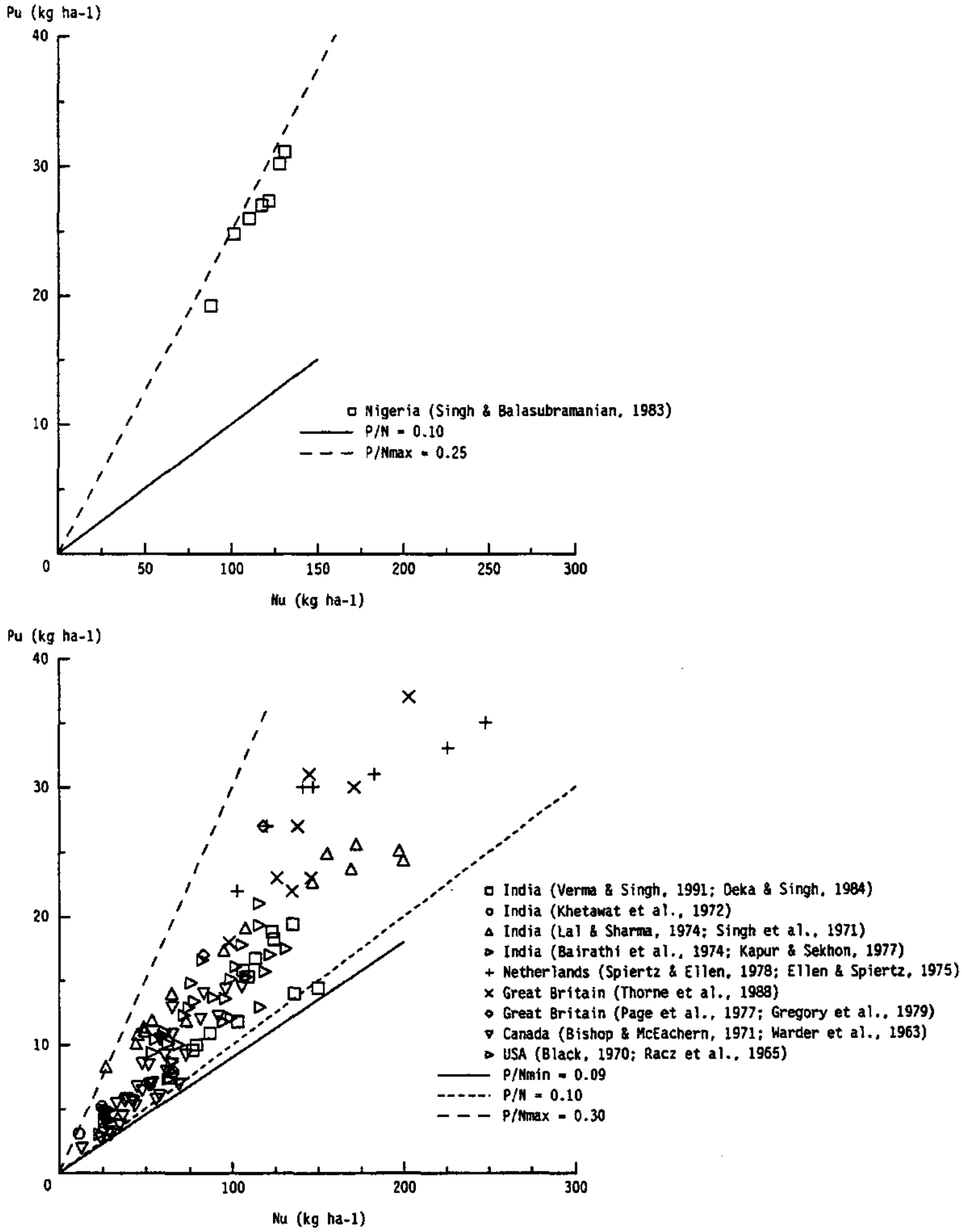


Figure 9.9. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of wheat, a) in West Africa and b) elsewhere.*

9.6 Relations among relative post-anthesis nutrient uptake values of N, P and K

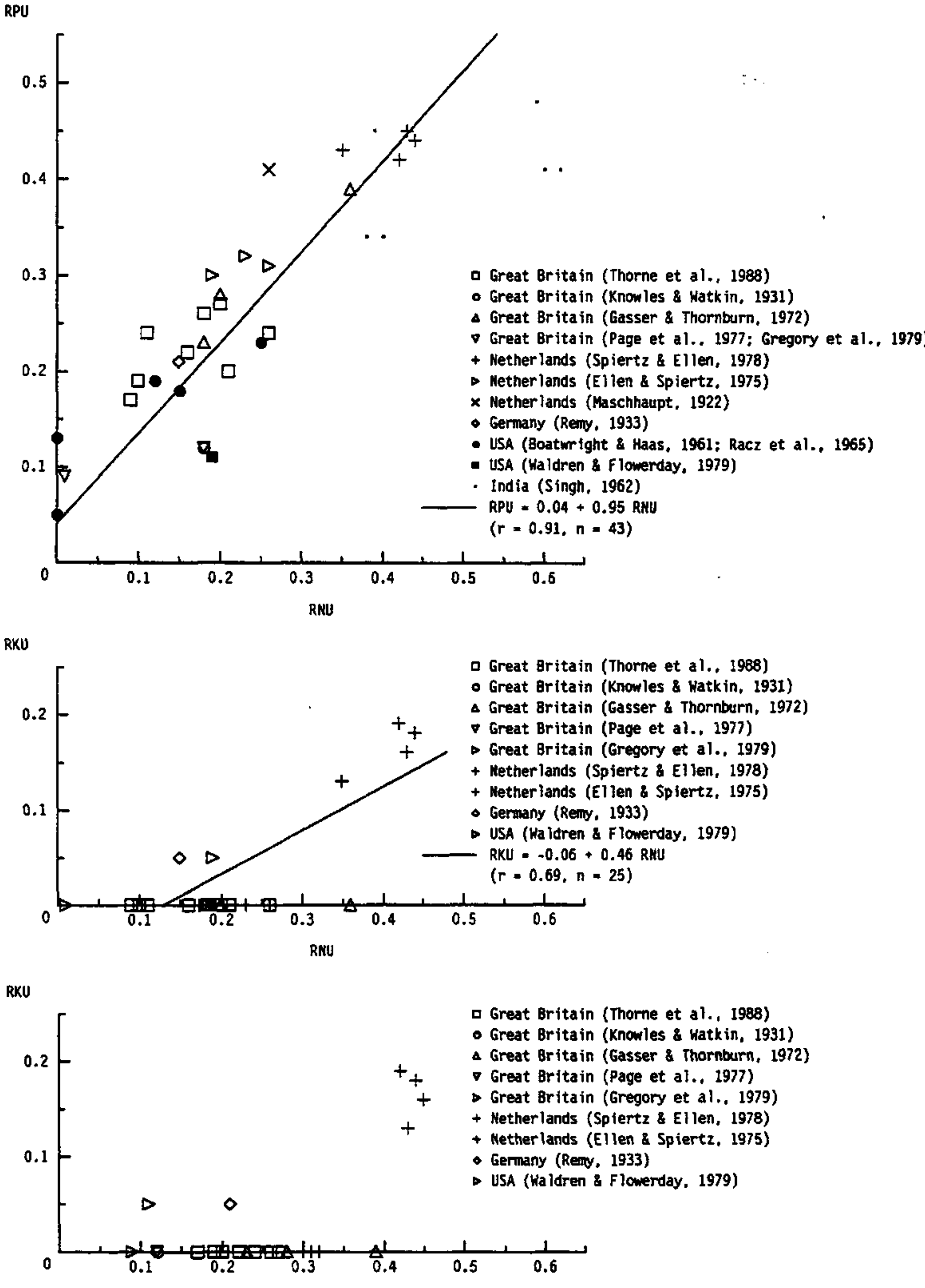


Figure 9.10. *Relationship between relative post-anthesis nutrient uptake in wheat of a) nitrogen and phosphorus, b) nitrogen and potassium and c) phosphorus and potassium. Line represents average regression line.*

9.7 Nutrient harvest indices

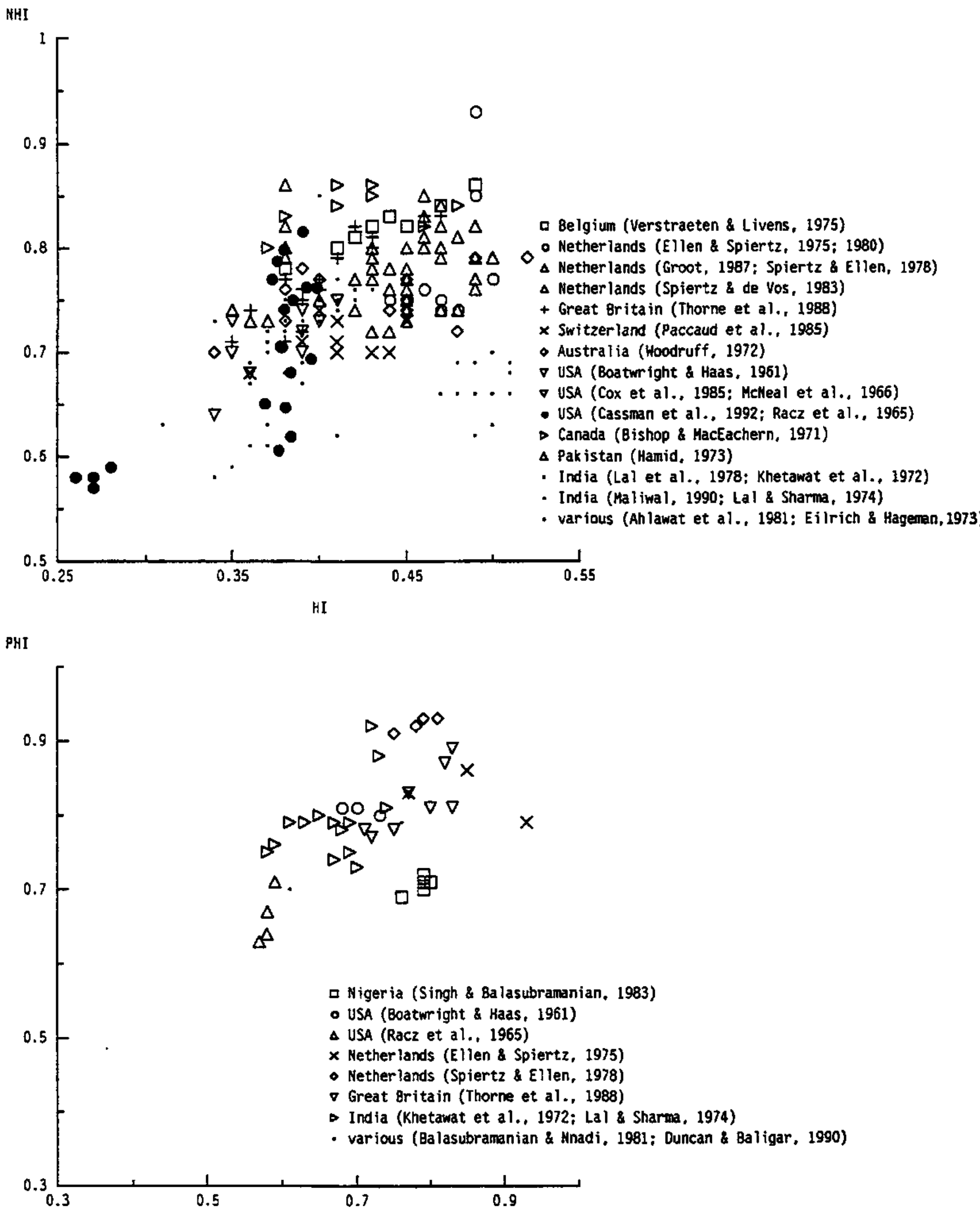


Figure 9.11. *Relation between a) harvest index and nitrogen harvest index and b) nitrogen harvest index and phosphorus harvest index of wheat. Line represents average regression line.*

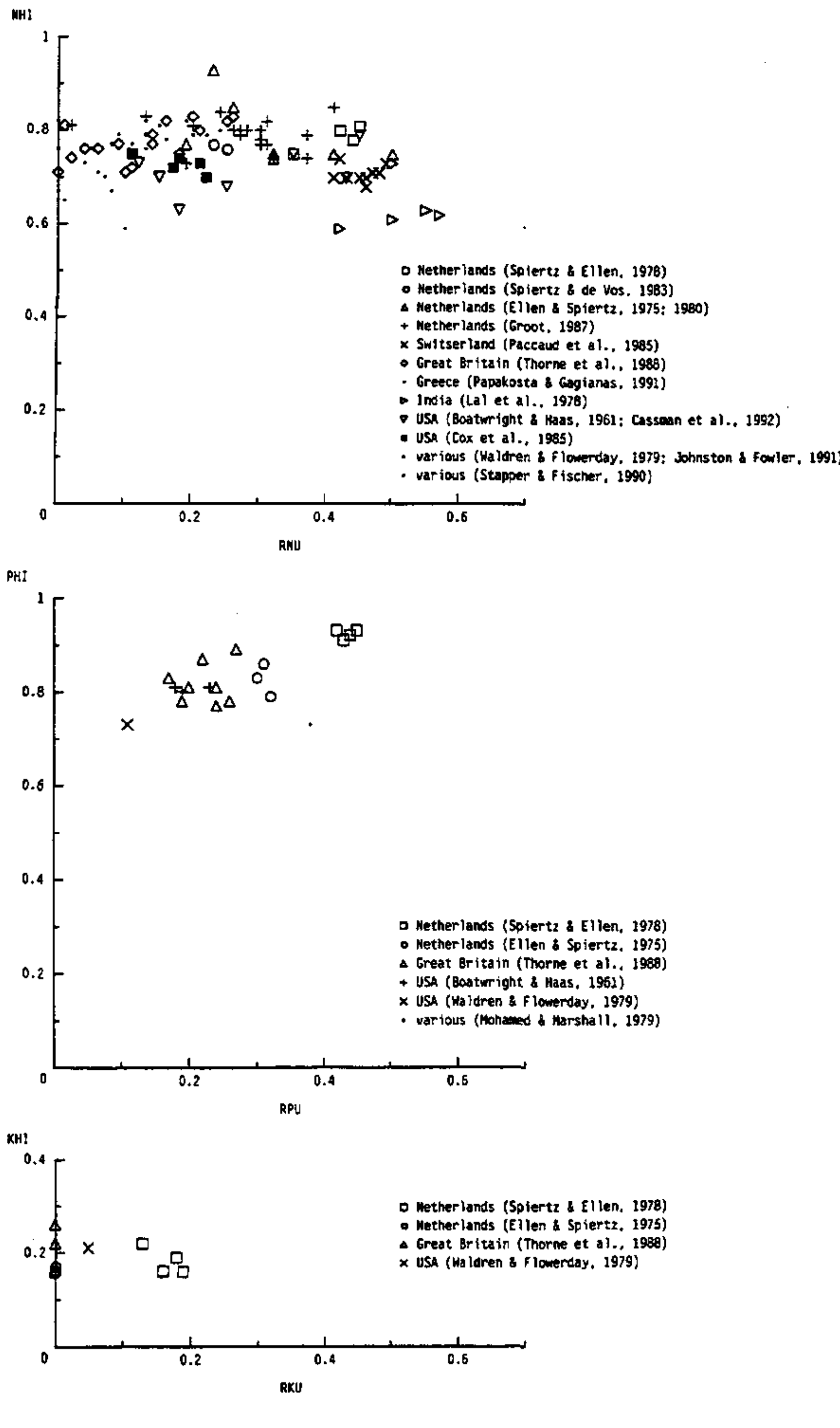


Figure 9.12. *Relation between relative post-anthesis nutrient uptake and nutrient harvest index in wheat for a) nitrogen, b) phosphorus and c) potassium. Line represents average regression line.*

10. FONIO

Experiments with fonio are limited available and relevant information for definition of fonio production techniques has been summarized by Gosseye (van Duivenbooden *et al.*, 1991, p.76-84).

10.1 Dry matter distribution

Table 10.1. *Average harvest indices (grain/total aboveground biomass) and their range in fonio. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	HI	range	n	REMARKS	SOURCE
Mali	0.28	0.23-0.32	2		Maiga *ea*, 1991
Senegal	0.30	0.26-0.33	3		Froment quoted by Portères, 1955
Netherlands	0.33	0.23-0.45	6	pot exp. soil 1	Cissé, 1975
	0.27	0.18-0.36	6	pot exp. soil 2	Cissé, 1975
	0.26	0.18-0.37	6	pot exp. soil 3	Cissé, 1975

As very limited data were available and because fonio easily shatters its grain at maturity, harvest index is relatively low and has been set arbitrarily at 0.15.

10.2 Concentration of major elements

Table 10.2. Minimum and maximum concentrations [g kg^{-1}] of major elements in straw, grains and total aboveground biomass of fonio; each line corresponds to one dataset (ea = et al.).

COUNTRY	STRAW min	STRAW max	GRAINS min	GRAINS max	SOURCE
Nitrogen					
Mali			13.3		quotations by Cissé, 1975
			12.3		Carbiener *ea*, 1960
General			13.9		Purseglove, 1975
General			13.8		RFMC, 1980
General	8.7				Göhl, 1982
General			10.3	13.5	quotations by Portères, 1955 1955
Phosphorus					
Mali			2.1		Busson quoted by Cissé, 1975
General			0.6		RFMC, 1980
Potassium					
Mali			2.8		Busson quoted by Cissé, 1975
Calcium					
General			0.7		RFMC, 1980
Sodium					
Mali			0.2		Busson quoted by Cissé, 1975
Magnesium					
Mali			0.9		Busson quoted by Cissé, 1975

With respect to the data in Table 10.2, the following remarks may be made. The minimum N-concentration in straw of 8.6 g kg^{-1} (Göhl, 1982) seems relatively high compared to those in millet and sorghum straw. The nutritional value of fonio straw, however, is considered superior to that of millet. Hence, in this study the minimum N-concentration is set at 5.0 g kg^{-1}. Moreover, the N-concentration in grains reported by RFMC (1980) is considered too low, a value of 12.3 g kg^{-1} being applied, which in combination with the applied minimum P-concentration (that of millet, due to absence of data) results in an acceptable P/N ratio. As data on P-and K-concentrations in fonio straw scarce, those of millet have been applied (0.3 and 10.0 g kg^{-1}, respectively, Table 4.1).

11. GROUNDNUT

11.1 Dry matter distribution

Results on dry matter distribution are presented as average (and ranges) of experiments (Table 11.1). Fruit harvest indices (FHI = grain+podshells to total aboveground biomass) are listed in Table 11.2 and the grain fruit ratio (GFR = grains to grains+podshells) in Table 11.3.

Table 11.1. *Average harvest indices (grain/total aboveground biomass) and their range in groundnut. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	HI	range	n	REMARKS	SOURCE
Niger	0.29		1		Bertrand *ea*, 1972
Nigeria	0.25		1		Balasubramanian & Nnadi, 1981
	0.36		1		Bromfield, 1973
	0.14	0.10-0.18	3		Bromfield, 1975
	0.26	0.24-0.29	3		Bromfield, 1975
	0.32	0.29-0.35	3		Bromfield, 1975
Senegal	0.34	0.33-0.35	11		Ganry, 1990
	0.11	0.10-0.11	3	T0,+lime,+manure	Ganry, 1990
	0.36	0.34-0.37	11	N-fert. exp.	Ganry, 1990
		0.23-0.37	12	200-1200 mm	Annerose, 1990
	0.14	0.26	12	waterstress 1	Annerose, 1990
	0.13	0.28	12	waterstress 2	Annerose, 1990
	0.11	0.28	12	waterstress 3	Annerose, 1990
	0.38		14		Pouzet, 1974
	0.45	0.43-0.46	4		Gillier, 1964

Table 11.2. *Average fruit-harvest indices (FHI, (grain+podshells)/ total aboveground biomass) and their range in groundnut. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY FHI	range	n	REMARKS	SOURCE
Burkina Faso				
0.49	0.45-0.54	6	saria	Ouattara *ea*, 1989
0.37	0.30-0.49	6	saria	Ouattara *ea*, 1989
Mali				
0.38	0.34-0.43	3	3 var.	Hulet, 1983
0.40	0.35-0.42	7	1973	Jenny, 1974
0.34	0.33-0.38	5	1973	Jenny, 1974
0.32	0.27-0.34	6	1972	Jenny, 1974
0.41	0.38-0.43	5	1972	Jenny, 1974
0.38	0.35-0.45	6	1972	Jenny, 1974
0.18	0.16-0.21	6	1972	Jenny, 1974
0.36	0.31-0.38	6	1972	Jenny, 1974
0.37	0.32-0.40	5	1971	Jenny, 1974
0.33	0.31-0.34	5	1971	Jenny, 1974
0.31	0.27-0.36	6	1970	Jenny, 1974
Niger				
0.31	0.24-0.35	3	1989, 3 cvs.	Bationo *ea*, 1991
0.20	0.11-0.31	9	1988, 9 cvs.*	ICRISAT, 1989
0.46	0.39-0.52	4	1988, 4 cvs.	ICRISAT, 1989
0.42	0.18-0.58	15	1988, 3 loc.1cv	ICRISAT, 1989
0.34	0.30-0.38	10	1988, 10 cvs.	ICRISAT, 1989
0.45	0.40-0.50	4	1987, 4 cvs.*	ICRISAT, 1989
0.38		1		Bertrand *ea*, 1972
0.44	0.43-0.45	2	1970	Nabos *ea*, 1974
0.44	0.37-0.60	2	1967-1972	Nabos *ea*, 1974
Nigeria				
0.50		1		Bromfield, 1973
0.27	0.21-0.31	3		Bromfield, 1975
0.37	0.35-0.41	3		Bromfield, 1975
0.45	0.41-0.50	3		Bromfield, 1975
Senegal				
0.45	0.44-0.46	11		Ganry, 1990
0.21	0.19-0.22	3	T0,+lime,+manure	Ganry, 1990
0.52	0.50-0.55	11		Ganry, 1990
0.35		1	1979, 351 mm	Piéri, 1983
0.58		1		Bockelee quoted by Piéri, 1983
0.56	0.52-0.62	10	1977	341 mm Piéri, 1979
0.46	0.42-0.48	10	1976 403 mm	Piéri, 1979
0.50	0.41-0.55	10	1975 574 mm	Piéri, 1979
0.57	0.53-0.61	10	1974 504 mm	Piéri, 1979
0.39	0.38-0.40	5	1973 402 mm	Piéri, 1979
0.51		1	197?	Pouzet, 1974

**) dry season with irrigation*

.../...

Table 11.2. *Continued.*

COUNTRY FHI	range	n	REMARKS	SOURCE
Senegal				
0.60	0.59-0.62	4	1964	Gillier, 1964
0.48	0.45-0.50	13	1962	Tourte *ea*, 1964
0.47	0.45-0.54	11	1960	Tourte *ea*, 1964
0.47	0.45-0.48	2	1986	Sené, 1989
0.51	0.50-0.52	2	1987	Sené, 1989
0.43	0.42-0.45	2	1987	Sené, 1989
0.04	0.04-0.05	2	1988	Sené, 1989
0.30	0.30-0.31	2	1988	Sené, 1989
0.35	0.35-0.36	2	1988	Sené, 1989
0.37	0.34-0.40	2	1988	Sené, 1989
0.39	0.39-0.40	2	1988	Sené, 1989

Table 11.3. *Grain-fruit ratio (GFR = grains/(grains+podshells)) of groundnut. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY GFR	range	n	REMARKS	SOURCE
Senegal				
0.77	0.76-0.78	11		Ganry, 1990
0.55	0.53-0.57	3	T0,+lime,+manure	Ganry, 1990
0.68	0.66-0.71	11		Ganry, 1990
0.74		14		Pouzet, 1974
0.74	0.72-0.74	4		Gillier, 1964
Niger				
0.54	0.46-0.62	9	9 cvs.	ICRISAT, 1989
0.78		1		Bertrand *ea*, 1972
Nigeria				
0.72		1		Bromfield, 1973
0.54	0.47-0.58	3		Bromfield, 1975
0.69	0.68-0.70	3		Bromfield, 1975
0.70	0.69-0.71	3		Bromfield, 1975

Target yield of groundnut comprises both grains and podshells, as the product is generally sold unshelled. As no simulation model has been used for this crop, stover production is based on fixed fruit harvest indices for extensive and semi-intensive systems of 0.45 and 0.50, respectively. The grain-fruit ratio is set at 0.70.

11.2 Concentration of major elements

With respect to data on nutrient concentrations in groundnut (Table 11.4), the P-concentration in straw reported by Gillier (1964) seems too low compared to the N-concentration, hence the value reported by Piéri (1979) has been applied.

Table 11.4. *Minimum and maximum concentrations [g kg^{-1}] of major elements in stover, grains and podshells of groundnut; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	HAULM		GRAINS		PODSHELLS		SOURCE
		min	max	min	max	min	max	
Nitrogen								
Gambia		19.0						Russo, 1986
Senegal	- fertilizer	11.9		56.7		10.9		Ganry, 1990
	+ fertilizer	11.9	15.3	54.2	57.6	9.2	12.8	Ganry, 1990
	- fertilizer	15.7		48.6		8.4		Ganry, 1990
	+ fertilizer	14.7	17.3	42.9	45.9	7.5	8.5	Ganry, 1990
	- fertilizer	11.6	21.9					Piéri, 1979
	+ fertilizer	12.1	22.5					Piéri, 1979
		12.2	21.2	43.4	47.8	7.0	8.4	Pouzet, 1974
	- NP fert.	13.2	15.2	44.5	46.6	9.6	10.8	Gillier, 1964
	+ NP fert.	15.3	16.6	47.5	51.0	10.9	13.4	Gillier, 1964
			16.9		47.5	9.1		Bertrand *ea*, 1972
						7.5		Piéri, 1989
		15.6	27.4					Ndiaye, 1978
			17.1			9.6		Richard *ea*, 1989
Nigeria						10.0		Balasubramanian & Nnadi, 1981
		15.2		39.1		8.1		Bromfield, 1973
		14.7						Okaiyeto, 1984
General		13.8	21.1					RFMC, 1980
General				34.7				Euroconsult, 1989
General				43.2				Sinclair & de Wit, 1975
General				43.2				Penning de Vries *ea*, 1983
Phosphorus								
Senegal	- fertilizer	1.0	2.6					Piéri, 1979
	+ fertilizer	1.1	2.5					Piéri, 1979
		1.1	2.0	3.3	4.1	0.4	0.5	Pouzet, 1974
	- NP fert.	0.5	1.6	2.2	4.0	0.4	0.6	Gillier, 1964
	+ NP fert.	0.5	1.2	2.3	3.8	0.5	0.7	Gillier, 1964
			1.1		3.6	0.4		Bertrand *ea*, 1972
						0.4		Piéri, 1989
		1.0	2.0					Ndiaye, 1978
			1.7			0.6		Richard *ea*, 1989
Nigeria						0.6		Balasubramanian & Nnadi, 1981
		1.5		3.5		0.6		Bromfield, 1973
				7.2	7.8			Bromfield, 1975
Colombia	incl. shells			3.1	3.3			Mason *ea*, 1986a,b
General		1.2	2.1					RFMC, 1980

.../...

Table 11.4. Continued.

COUNTRY	REMARKS	HAULM min	HAULM max	GRAINS min	GRAINS max	PODSHELLS min	PODSHELLS max	SOURCE
Potassium								
Senegal	- fertilizer	8.2	13.5					Piéri, 1979
	+ fertilizer	9.5	26.3					Piéri, 1979
		7.4	19.5	6.6	8.1	4.0	7.6	Pouzet, 1974
	- NP fert.	6.4	10.3	6.0	7.5	5.6	6.3	Gillier, 1964
	+ NP fert.	7.5	10.5	6.1	7.4	5.6	6.1	Gillier, 1964
			16.7		7.4	5.8		Bertrand *ea*, 1972
						5.6		Piéri, 1989
		3.4	17.2					Ndiaye, 1978
Nigeria						9.0		Balasubramanian & Nnadi, 1981
Colombia	incl. shells			7.5	7.7			Mason *ea*, 1986a,b
Calcium								
Senegal	- fertilizer	9.5	14.4					Piéri, 1979
	+ fertilizer	9.0	15.5					Piéri, 1979
		6.8	10.8	0.4	0.6	0.5	1.6	Pouzet, 1974
			8.2	0.3		0.7		Bertrand *ea*, 1972
						0.8		Piéri, 1989
		7.2	15.1					Ndiaye, 1978
			10.0				1.9	Richard *ea*, 1989
Nigeria						2.5		Balasubramanian & Nnadi, 1981
General		8.0	14.1					RFMC, 1980
Magnesium								
Senegal	- fertilizer		8.0					Piéri, 1979
	+ fertilizer	2.2	7.0					Piéri, 1979
		4.2	10.0	1.8	2.5	0.6	0.9	Pouzet, 1974
		4.9		1.7		0.6		Bertrand *ea*, 1972
						0.7		Piéri, 1989
		4.2	7.5					Ndiaye, 1978
			6.4					Richard *ea*, 1989
Nigeria						1.0		Balasubramanian & Nnadi, 1981
Sulphur								
Senegal		1.7	2.2	2.2	4.1	0.9	1.4	Pouzet, 1974
			1.9	2.3		1.0		Bertrand *ea*, 1972
Nigeria						1.0		Balasubramanian & Nnadi, 1981
		1.6		2.2		0.8		Bromfield, 1973
		0.7	2.0	1.1	2.1	0.3	1.0	Bromfield, 1975
Sodium								
Senegal			0.6					Richard *ea*, 1989

11.3 Three quandrant figures

11.3.1 Nitrogen

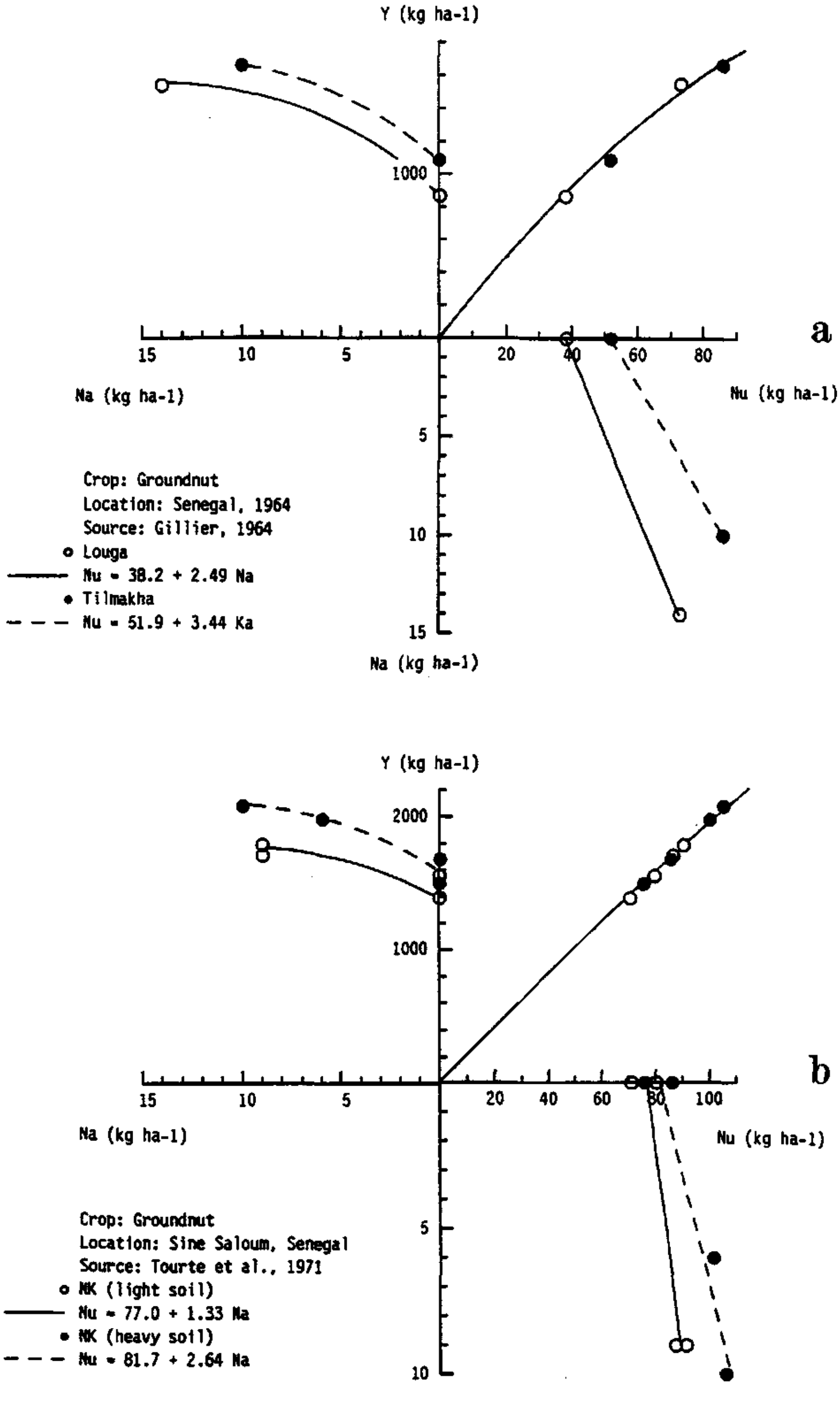
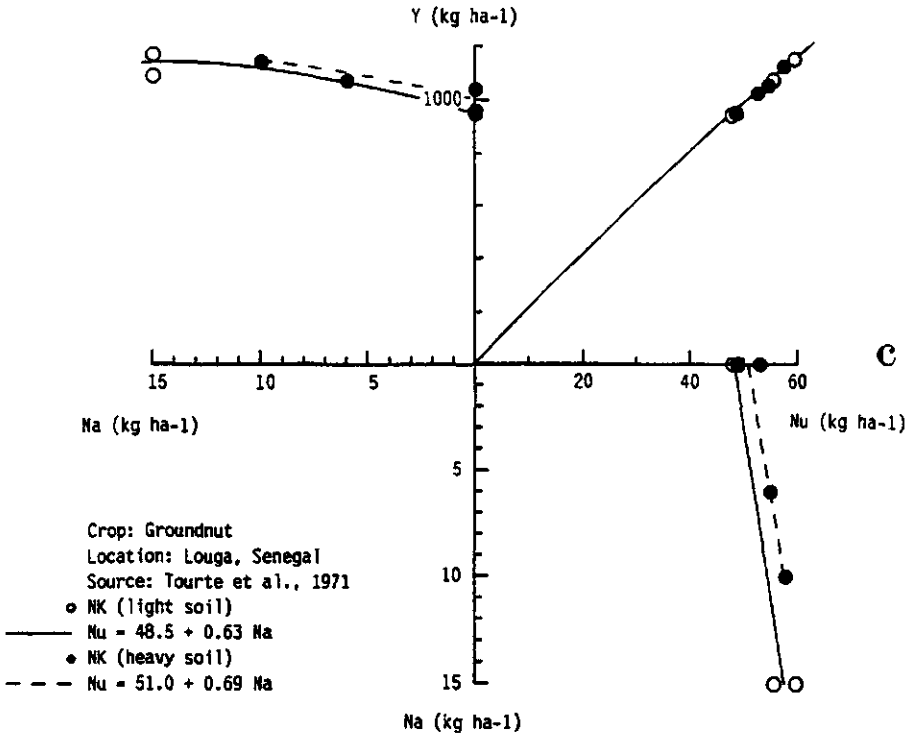


Figure 11.1. *Relation between total nitrogen content (N_u) and yield (Y), that between nitrogen application (N_a) and nitrogen content, and that between nitrogen application and yield.*



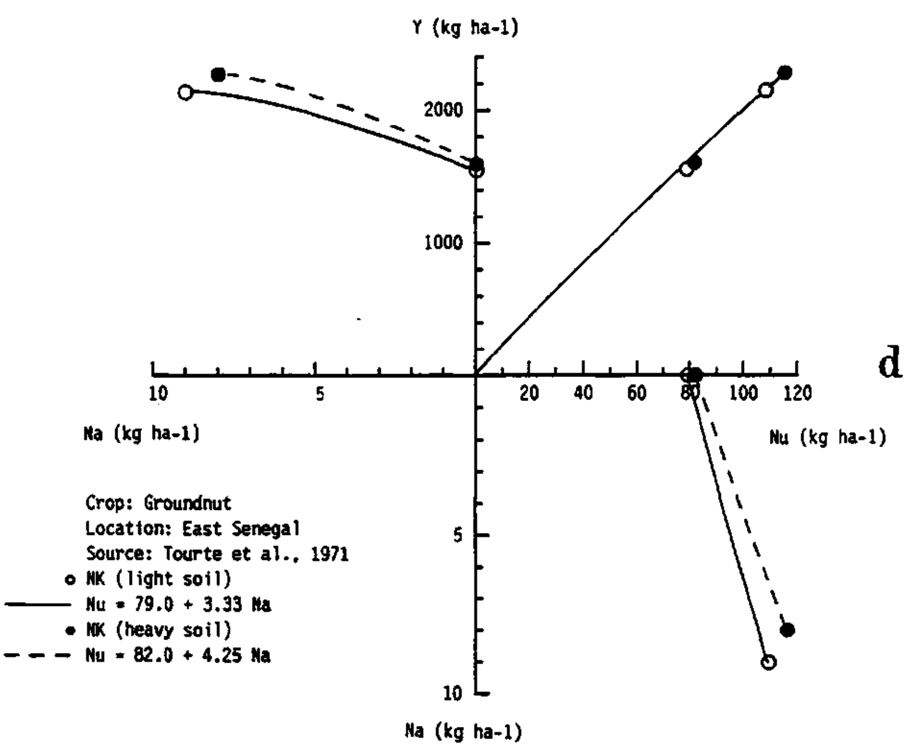
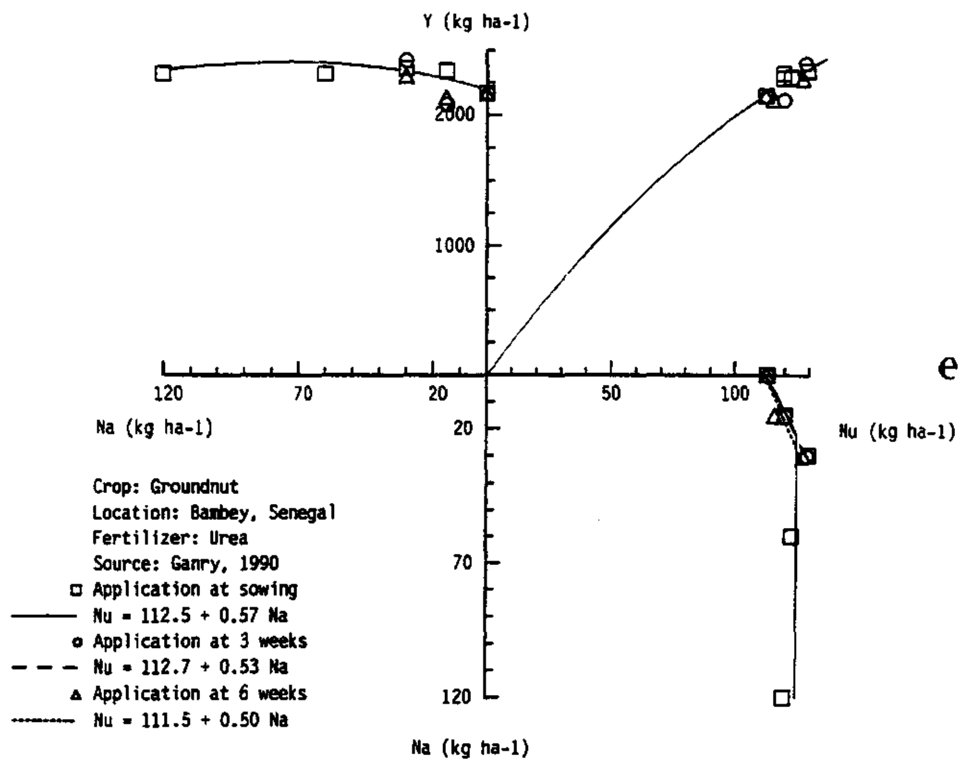


Figure 11.1. Continued.



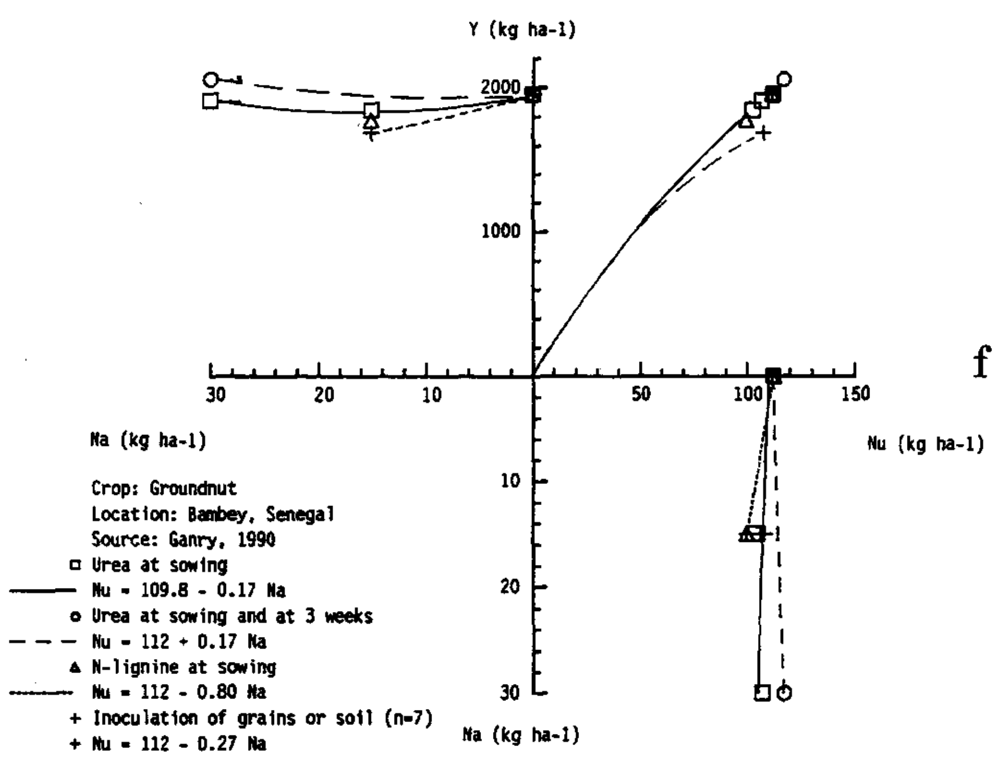


Figure 11.1. *Continued.*

11.3.2 Phosphorus

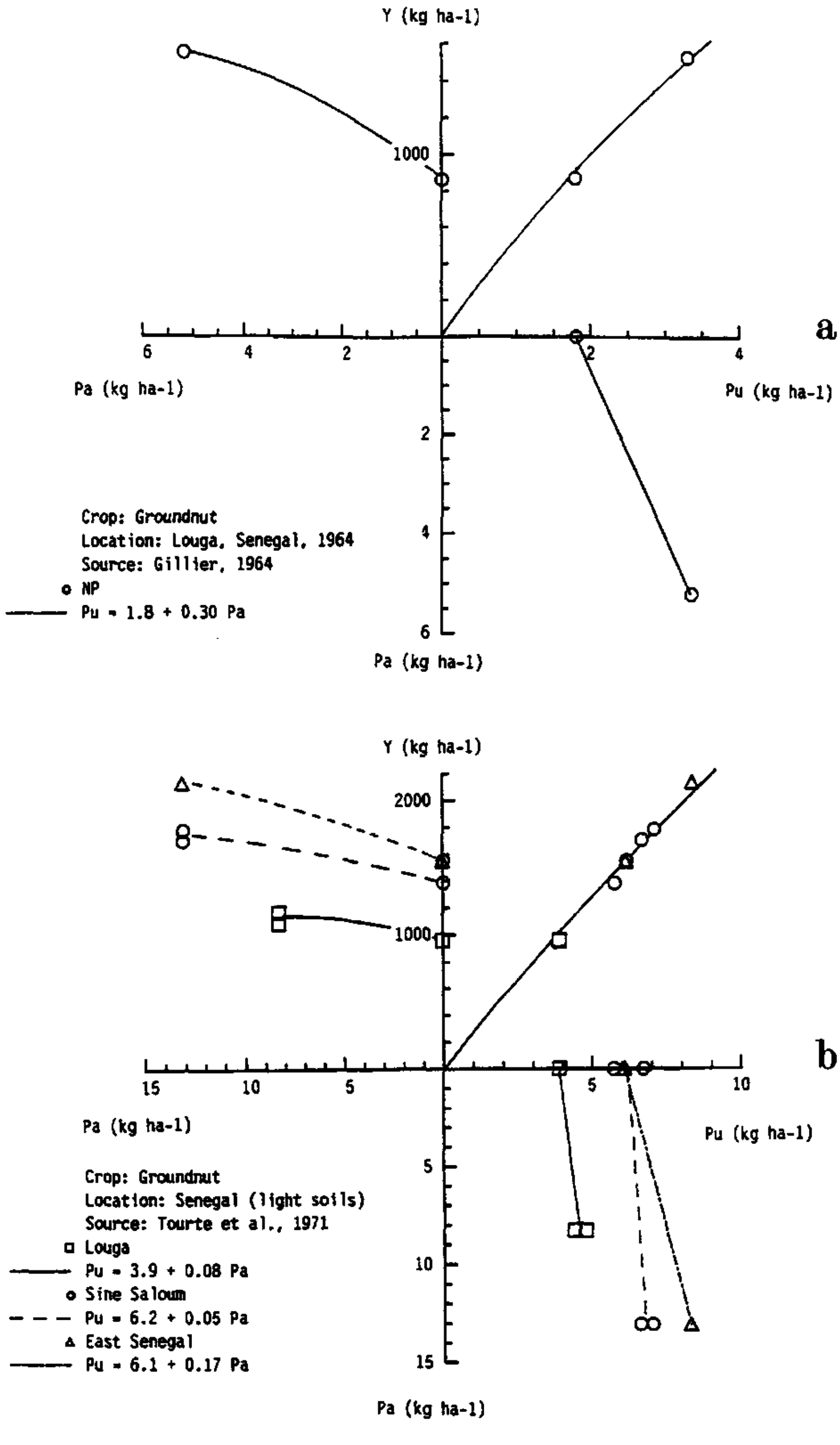


Figure 11.2. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*

11.3.3 Potassium

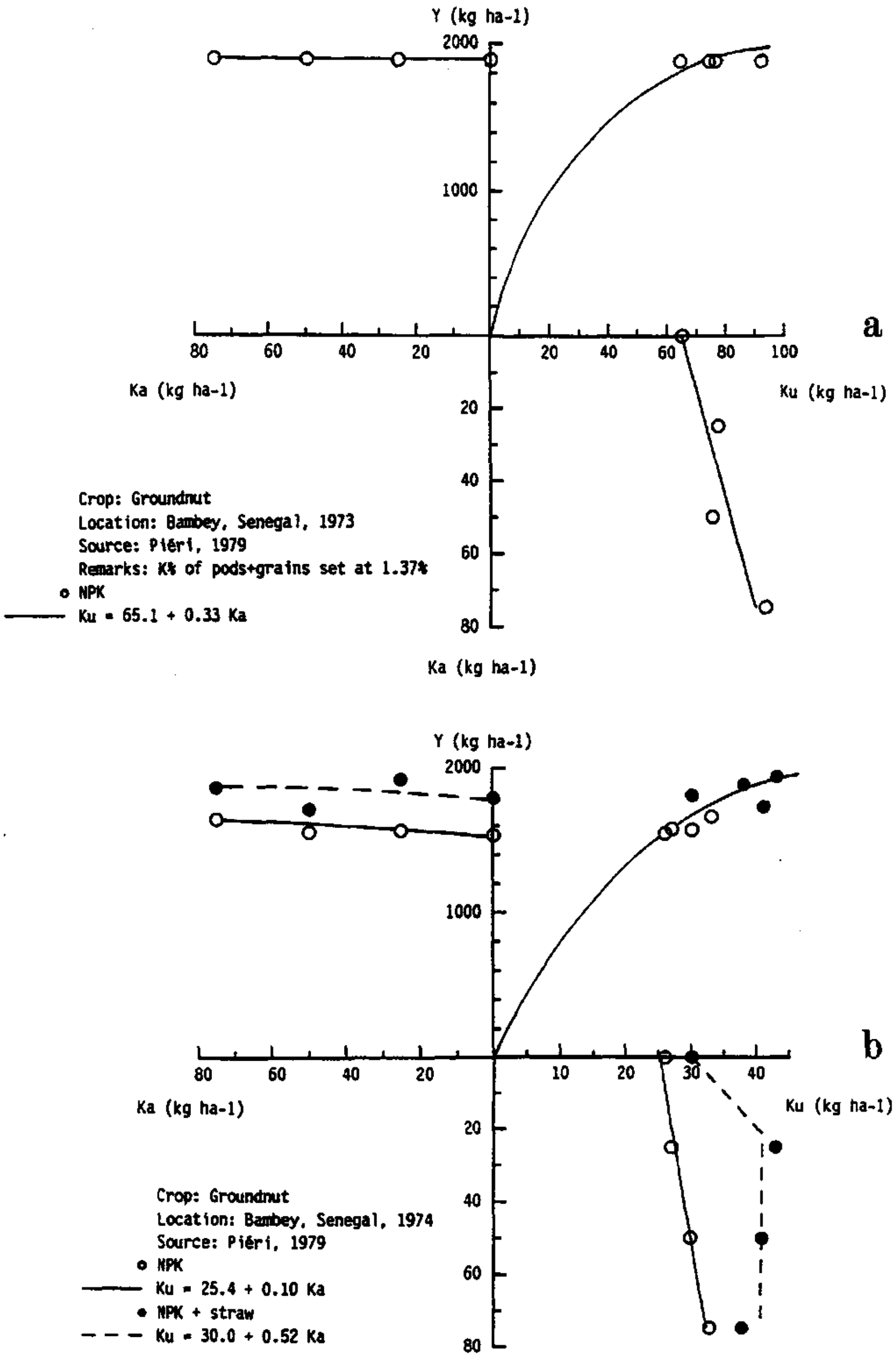
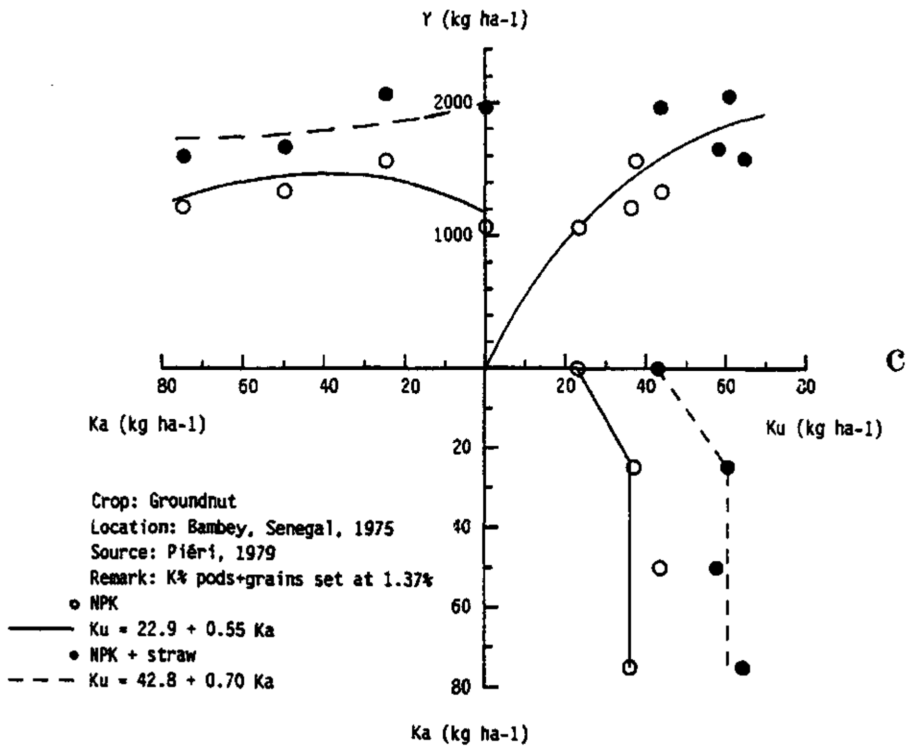


Figure 11.3. *Relation between total potassium content (K_u) and yield (Y), that between potassium application (K_a) and potassium content, and that between potassium application and yield.*



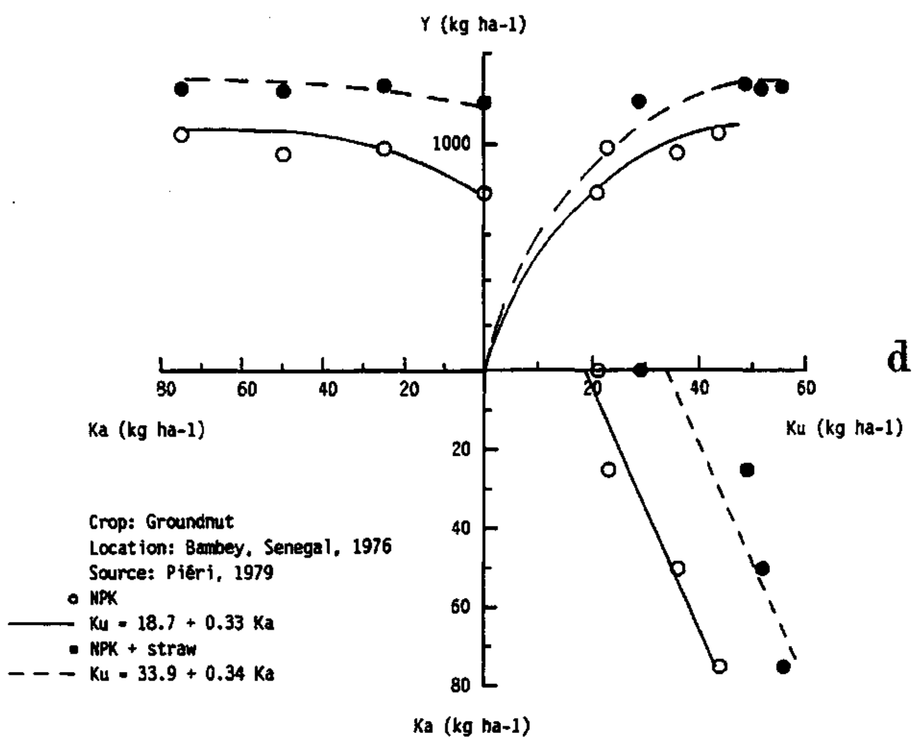


Figure 11.3. Continued.

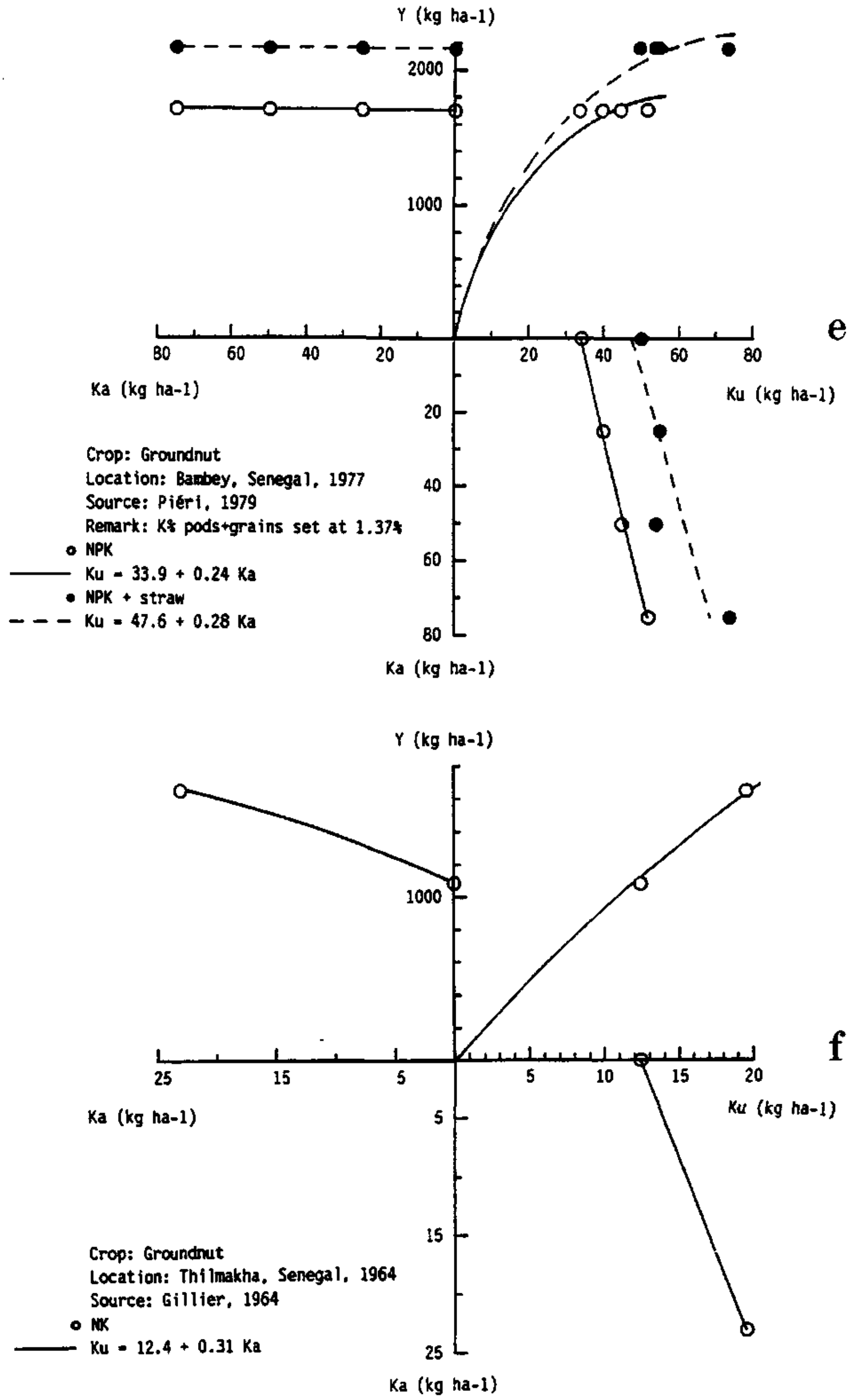


Figure 11.3. Continued.

11.4 Nutrient content as related to yield

The relation yield/N-content is illustrated in Figure 11.4. The nitrogen sources have been quantified in Table 11.5. For phosphorus, the relation yield/content is illustrated in Figure 11.5. The relation total aboveground biomass/K-content is presented in Figure 11.6. Due to time restriction no comparison has been made with experiments outside West Africa.

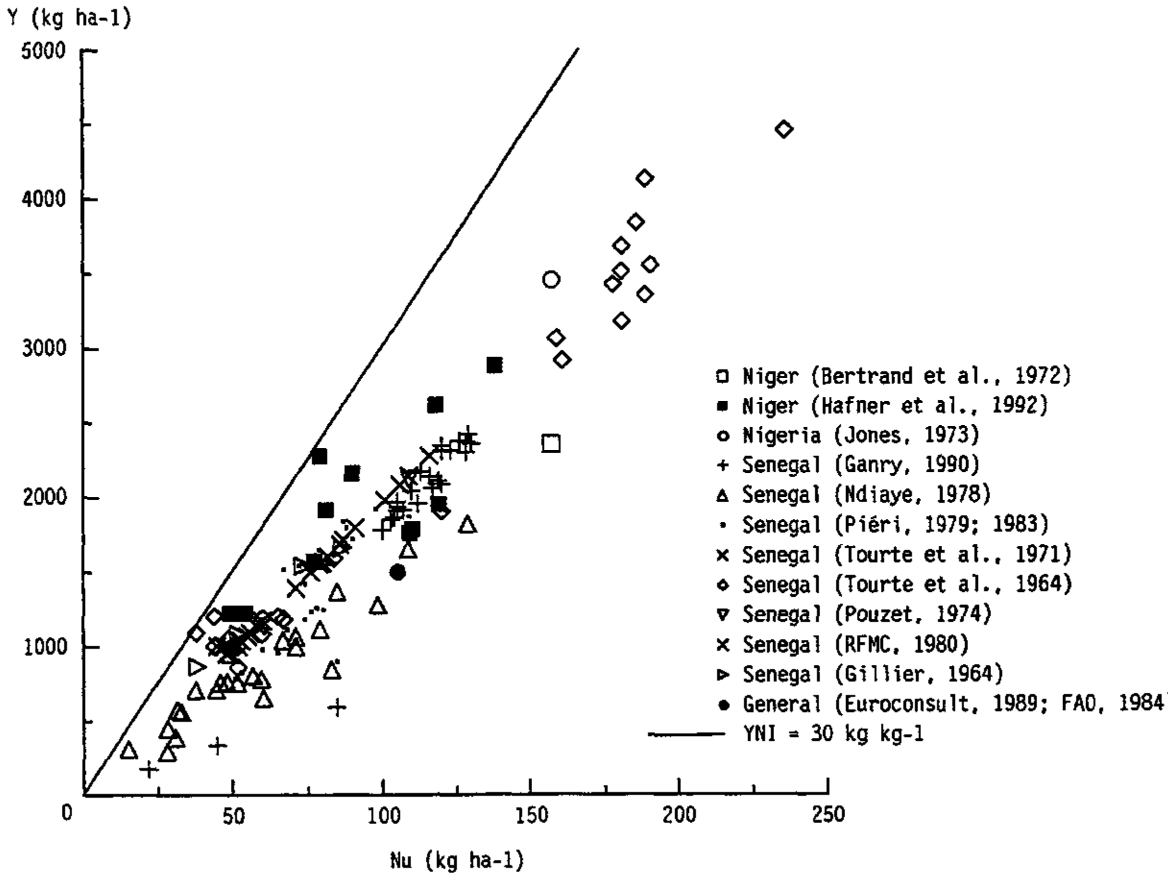


Figure 11.4. Relation between total nitrogen content (N_u) and yield of grains plus podshells (Y) of groundnut in West Africa; YNI = initial slope.

Table 11.5. *Total dry matter production and nitrogen uptake (kg ha^{-1}) by groundnut and its N-sources (%) by fixation (Fix), from fertilizer (Fert) and soil. • = unknown.*

DMtot	DMgrain	Nu	Fix	Fert	Soil	Country	Source
•	1 420	74	66	2	32	Senegal	Piéri, 1983[a]
•	1 126	59	21	4	75	Senegal	Piéri, 1983[b]
•	•		60-70			Senegal	Ganry quoted by Gigou, 1985
•	•	16	67	7	26	Senegal	Ganry, 1990
•	•	45	82	4	14	Senegal	Ganry, 1990[c]
•	•	85	74	2	24	Senegal	Ganry, 1990[d]
•	•	85	75	2	24	Senegal	Ganry, 1990[e]
•	•	103	65	3	32	Senegal	Ganry, 1980
•	•	77	21	5	74	Senegal	Ganry, 1980
•	•	75				Mali	Penning de Vries, 1982
USED			70				

a) precipitation sufficient;
b) precipitation low and unfavourable distribution;
c) with lime;
d) with farmyard manure;
e) average of 6 inoculated varieties + 1 blank.

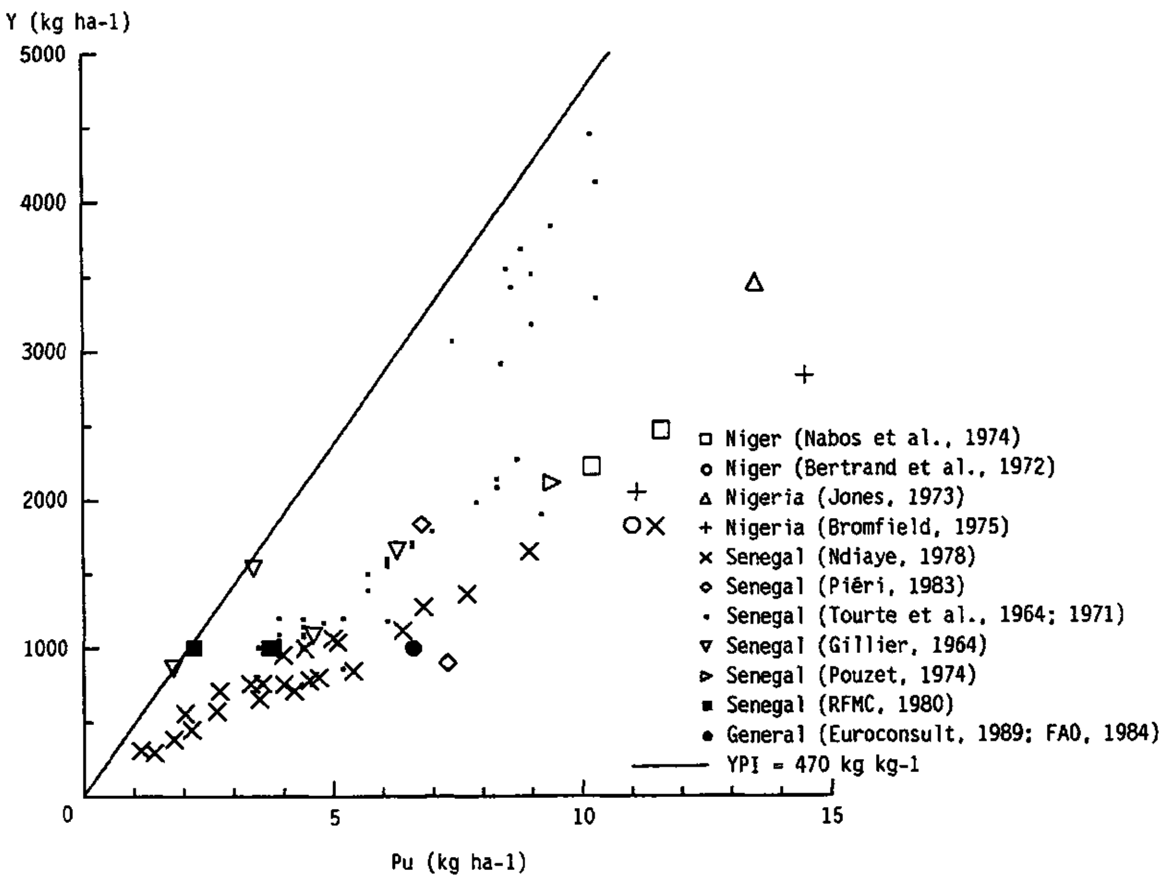


Figure 11.5. *Relation between total phosphorus content (P_u) and yield (Y) of groundnut in West Africa; YPI = initial slope.*

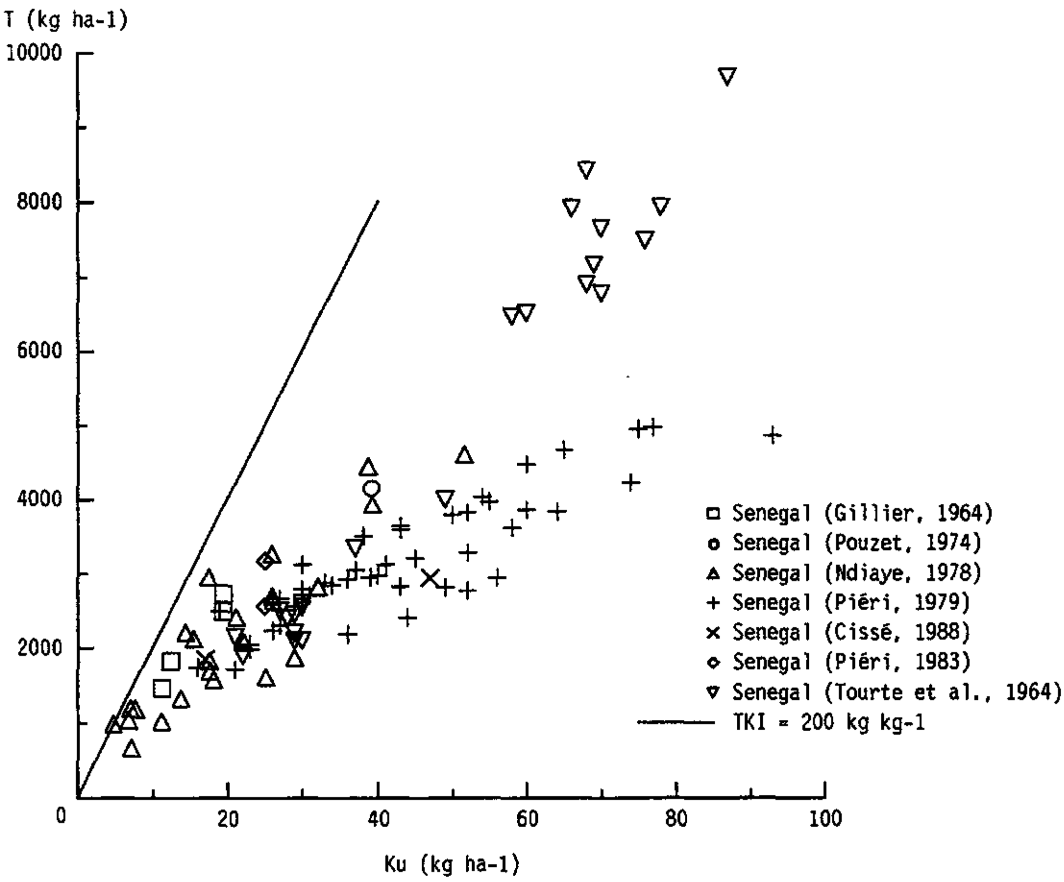


Figure 11.6. Relation between total potassium content (K_u) and total aboveground dry matter (T) of groundnut in West Africa; TKI = initial slope.

11.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 11.7; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

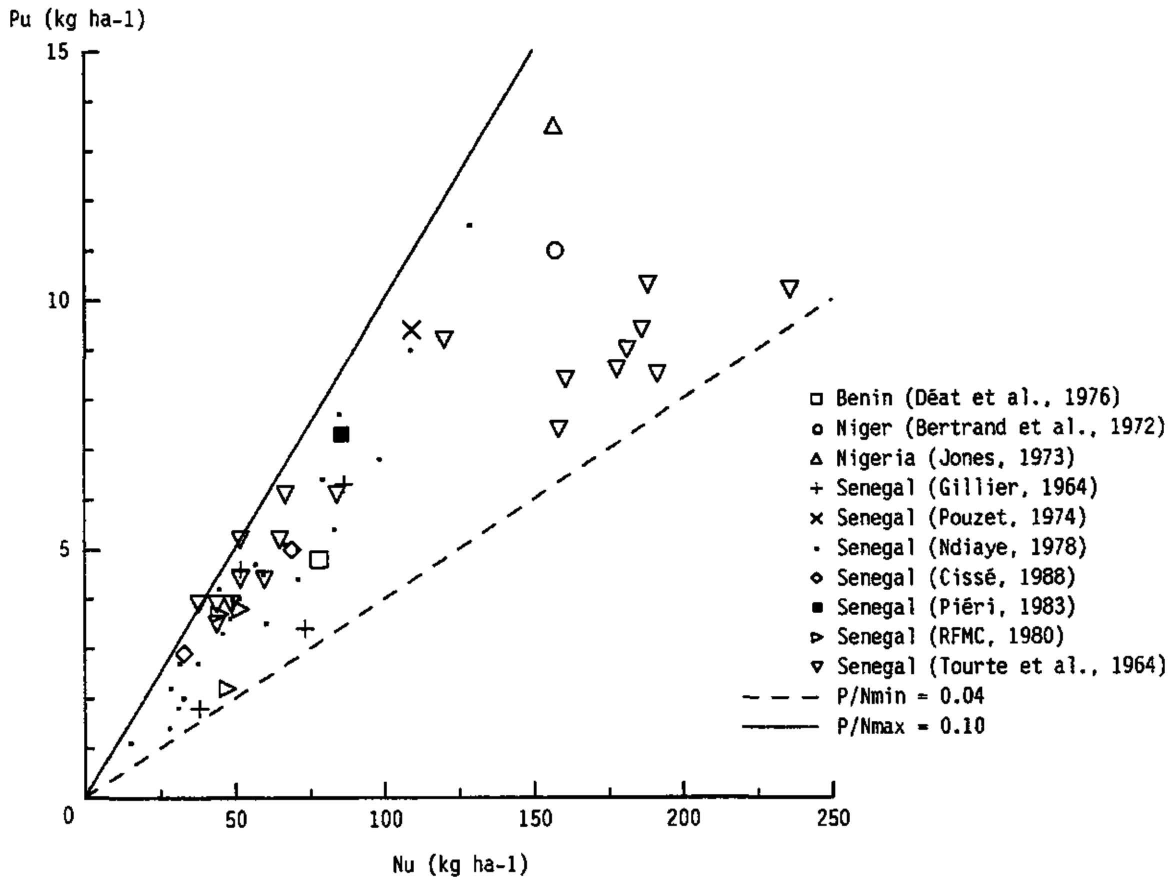
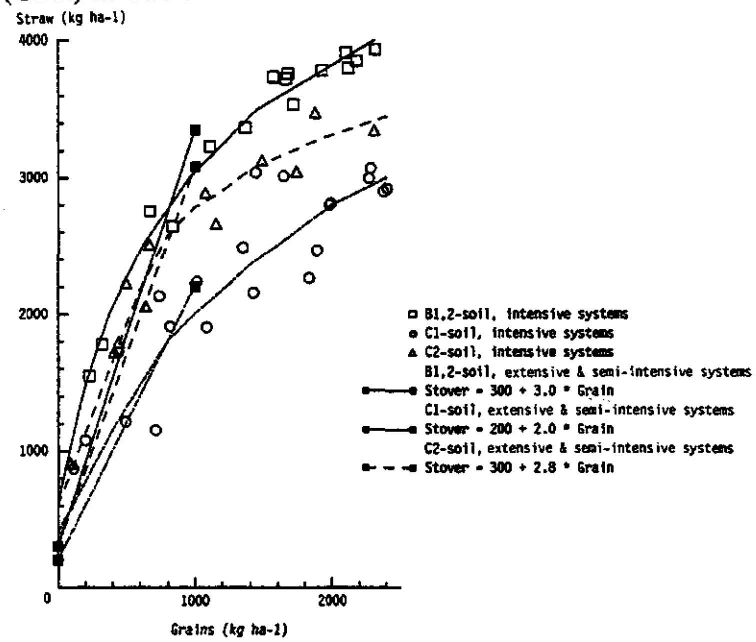


Figure 11.7. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of groundnut in West Africa.*

12. COWPEA

12.1 Dry matter distribution

Results on dry matter distribution are presented on the basis of simulation results as the relation grain to straw (Figure 12.1) and as average (and ranges) of experiments (Table 12.1). Fruit harvest indices (FHI) are listed in Table 12.2 and the grain fruit ratio (GFR) in Table 12.3.



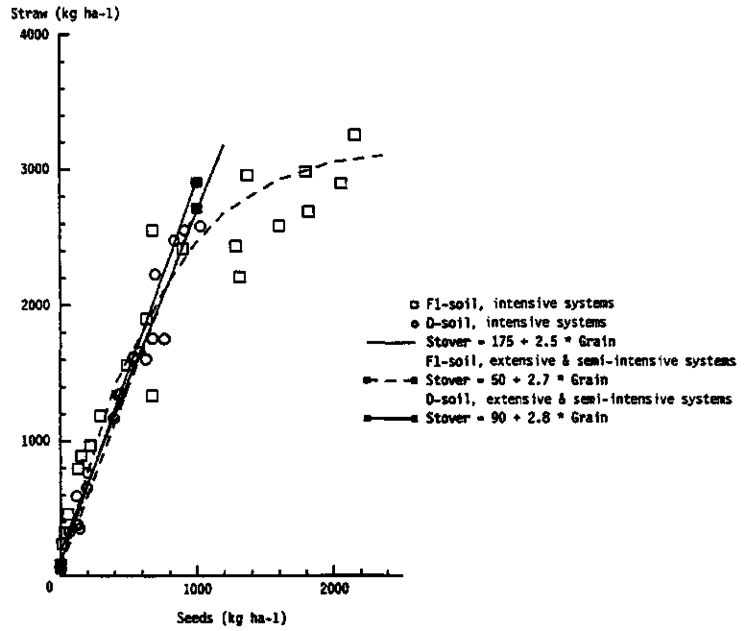


Figure 12.1. Simulated relationship of cowpea stover and grain production for intensive production systems and estimated relationship for extensive and semi-intensive production systems.

Table 12.1. *Average harvest indices (grain/total aboveground biomass) and their range in cowpea. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	HI	range	n	REMARKS	SOURCE
Mali	0.10	0.00-0.22	6		Hulet, 1985b
	0.17	0.00-0.32	20	20 cv.	Hulet, 1985a
	0.20	0.09-0.32	7	CSIRO 45581 *)	Hulet, 1985a
	0.12	0.02-0.27	8	CSIRO 57317 *)	Hulet, 1985a
	0.11	0.02-0.37	11	CSIRO 57317 *)	Hulet, 1985a
	0.13	0.00-0.24	10	TN 88-63 *)	Hulet, 1985a
	0.11	0.00-0.16	4	TN 88-63 *)	Hulet, 1985a
	0.09	0.03-0.17	6	6 var. *)	Hulet, 1985a
	0.10		22	2 cv.	Hulet, 1984
	0.04			20 cv.	Hulet, 1983
Niger	0.32	0.07-0.56	2	IT84E1-108 irr.	Sivakumar, 1990
	0.32	0.26-0.40	10	Fert. exp, 1989	Bationo *ea*, 1991
Nigeria	0.44	0.39-0.45	3	noninoculated	Awonaike *ea*, 1990
	0.43	0.30-0.52	6	inoculated	Awonaike *ea*, 1990
	0.30	0.27-0.33	10	Ife Brown 1983	Tayo, 1986
	0.24	0.14-0.30	10	Ife Brown 1984	Tayo, 1986
	0.31	0.25-0.33	10	Tvx 3236 1984	Tayo, 1986
	0.35	0.21-0.43	5	Greenhouse exp.	Ojehomon, 1970
	0.32	0.25-0.39	3	Field exp.	Ojehomon, 1970
	0.26		1		Balasubramanian & Nnadi, 1981
Australia	0.21	0.19-0.22	3		Ofori & Stern, 1987
	0.22	0.16-0.28	4	1982/83	Ofori & Stern, 1986
	0.37	0.33-0.42	3	Dry--wet	Chapman & Muchow, 1985
	0.57	0.56-0.59	3	1967-1977	Lawn, 1982
	0.42	0.34-0.48	3	1978	Lawn, 1982
Costa Rica	0.40	0.39-0.40	3		Chang & Shibles, 1985
India	0.17	0.16-0.18	10		Bansal & Singh, 1975
UK	0.39	0.39-0.40	5	pot exp.	Huxley, 1980
	0.35	0.34-0.38	7	pot exp.	Minchin *ea*, 1976
	0.43	0.40-0.46	7	pot exp.	Minchin *ea*, 1976
	0.43		1	pot exp.	Eaglesham *ea*, 1977
	0.56	0.48-0.61	8	pot exp.	Summerfield *ea*, 1978
COWPEA INTERCROPPED					
Mali	0.06	0.03-0.12	8	Intercr. 1985	Hulet, 1988
Niger	0.30	0.23-0.35		Intercr. 1985	Ntare, 1989
	0.40	0.28-0.47		Intercr. 1986	Ntare, 1989
Australia	0.30	0.25-0.34	4	Intercr.	Ofori & Stern, 1986
	0.27	0.24-0.31	6	Intercr.	Ofori & Stern, 1986

*) farmers fields

Table 12.2. *Average fruit-harvest indices (FHI, (grain+podshells)/total aboveground biomass) and their range in cowpea. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	FHI	range	n	REMARKS	SOURCE
Nigeria	0.30	0.24-0.36	3	3 varieties	Nnadi *ea*, 1976
	0.35	0.17-0.53	3	3 varieties	Eaglesham *ea*, 1982a
Senegal	0.62	0.45-0.72	4	various cv.	Jacquinot, 1967
UK	0.46	0.45-0.46	5	pot exp.	Huxley, 1980
	0.49		1	pot exp.	Eaglesham *ea*, 1977

Table 12.3. *Grain-fruit ratio (GFR = grains/(grains+podshells)) of cowpea. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	GFR	range		n	REMARKS	SOURCE
Mali	0.67	0.63	0.70	8	intercrop	Hulet, 1988
	0.69	0.35	0.79	19	1984, 19 var.	Hulet, 1985a
	0.63	0.58	0.70	7	CSIRO 45581 *)	Hulet, 1985a
	0.57	0.23	0.71	8	CSIRO 57137 *)	Hulet, 1985a
	0.59	0.33	0.70	11	CSIRO 57137 *)	Hulet, 1985a
	0.62	0.50	0.77	9	TN 88-63 *)	Hulet, 1985a
	0.71	0.65	0.77	5	TN 88-63 *)	Hulet, 1985a
	0.56	0.48	0.74	6	6 var. *)	Hulet, 1985a
	0.50	0.50	0.50	2	1983, trial a	Haverman, 1986
	0.53	0.44	0.56	8	1983, trial b	Haverman, 1986
	0.64	0.56	0.67	4	1983, trial c	Haverman, 1986
	0.63	0.62	0.64	3	1983, trial d	Haverman, 1986
	0.62			90	WEIGHTED AVERAGE	
Sierra Leone	0.43	0.35	0.47	5	N-fert.exp.	Godfrey-Sam-Aggrey, 1975
UK	0.87	0.86	0.87	5	pot exp.	Huxley, 1980
	0.87			1	pot exp.	Eaglesham *ea*, 1977
	0.85	0.84	0.87	7	pot exp.	Minchin *ea*, 1976
	0.74	0.70	0.78	7	pot exp.	Minchin *ea*, 1976

*) farmers fields

Target yield of cowpea comprises only grains, as the product is generally sold shelled. The production of podshells is calculated on the basis of a fixed grain-fruit ratio of 0.60 and 0.70 for extensive and intensive systems, respectively.

12.2 Concentration of major elements

Table 12.4. *Minimum and maximum concentrations [g kg^{-1}] of major elements in stover, grains and podshells of cowpea; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	PODS min	PODS max	SOURCE
Nitrogen								
Mali		29.1	40.4					Genotte, 1988
	trial a	23.6	29.5	41.6	42.1	11.7	16.4	Haverman, 1986
	trial b	21.3	25.5	41.2	46.4	10.7	14.5	Haverman, 1986
	trial c	24.4	26.0	38.1	55.0	12.7	19.4	Haverman, 1986
	trial d	21.0	37.3	44.8	53.4	17.8	23.4	Haverman, 1986
Nigeria	Ife Brown			24.4	40.0			Kayode, 1990
			28.0				20.8	Göhl, 1982
				36.4	43.6			Fox *ea*, 1977
		16.0						Okaiyeto, 1984
	pot exp. IV76			39.6	44.7			Evans *ea*, 1977
	pot exp. IV201			40.8	49.3			Evans *ea*, 1977
	pot exp. Sitao			44.0	50.0			Evans *ea*, 1977
	3 var.	14.8	18.3	40.5	45.4			Nnadi *ea*, 1976
	37 var.			36.7	53.7			Evans & Boulter, 1974
	TN5-78	5.4	5.8	14.3	15.4			Reddy *ea*, 1992
Senegal	various	12.0	17.9	33.9	43.0	6.3	24.6	Jacquinot, 1967
			24.0					Richard *ea*, 1989
Australia		20	24	31	33			Ofori & Stern,
	Intercr.	17	23	31	33			1987
		14			42			Ofori & Stern,
	Intercr.	12	13	39	43			1986
	dry - wet	12.8	18.7	39.4	44.7			Chapman & Muchow, 1985
General				41.6				Sinclair & de Wit, 1975
				35.2				Purseglove, 1975
				38.4				Skerman *ea*, 1988
		22.4		40.2				RFMC, 1980
				42.9				Euroconsult, 1989
Indonesia		15.5	15.8	39.8	43.3	24.8	28.3	Sisworo *ea*, 1990
		15.8	16.7	39.6	43.9	26.7	28.3	Sisworo *ea*, 1990
UK	pot exp.			30.7	32.4	10.8	11.5	Huxley, 1980
	pot exp.			29.9	36.2	11.7	13.4	Dart *ea*, 1977
	pot exp.			31.7	36.9	11.0	14.0	Dart *ea*, 1977
	pot exp.				33.3		12.2	Eaglesham *ea*,1977
	pot exp.			35	38	13.0	15.0	Summerfield *ea*, 1978
USA	temp. exp.			36.0	49.0			Warrag & Hall, 1984

.../...

Table 12.4. Continued.

COUNTRY	REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	PODS min	PODS max	SOURCE
Phosphorus								
Mali		0.9	1.3					Genotte, 1988
	trial a	1.2	1.6	4.2	6.3	0.9	1.8	Haverman, 1986
	trial b	1.6	3.7	3.1	5.1		1.2	Haverman, 1986
	trial c	1.1	1.8	1.5	2.4	0.7	1.2	Haverman, 1986
	trial d	0.9	1.6	2.4	3.2	1.1	1.3	Haverman, 1986
Nigeria	various			4.4	5.4			Fox *ea*, 1977
	3 var.	1.5	1.9	5.9	6.2			Nnadi *ea*, 1976
Senegal	various	1.8	4.5	4.8	5.2	2.2	3.0	Jacquinot, 1967
			4.5					Richard *ea*, 1989
Colombia				2.8				Mason *ea*, 1986b
Costa R.						2.3	2.9	Chang & Shibles, 1985
USA	temp. exp.			4.0	5.0			Warrag & Hall, 1984
				4.2	4.6			Labanauskas *ea*, 1981
General		2.9		3.4				RFMC, 1980
Potassium								
Nigeria	various			15.0	18.0			Fox *ea*, 1977
	3 cv.	22.7	24.0	15.4	15.8			Nnadi *ea*, 1976
Senegal	4 cv.	8.9	16.9	20.2	21.2	10.8	12.4	Jacquinot, 1967
Colombia	incl.podshells			12.4	12.5			Mason *ea*, 1986b
USA	temp. exp.			13.0	14.0			Warrag & Hall, 1984
				11.8	15.8			Labanauskas *ea*, 1981
Calcium								
Nigeria				1.0	1.1			Fox *ea*, 1977
	3 var	20.6	25.7	1.0	1.1			Nnadi *ea*, 1976
Senegal		14.6						Richard *ea*, 1989
USA				0.8	1.3			Warrag & Hall, 1984
				2.0	2.3			Labanauskas *ea*, 1981
General		6.4		1.3				RFMC, 1980
Magnesium								
Nigeria				2.1	2.3			Fox *ea*, 1977
	3 var	3.2	4.8	2.1	2.2			Nnadi *ea*, 1976
Senegal			6.8					Richard *ea*, 1989
USA				1.7	1.9			Warrag & Hall, 1984
				1.8	1.9			Labanauskas *ea*, 1981

.../.

Table 12.4. Continued.

COUNTRY	REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	PODS min	PODS max	SOURCE
Sulphur								
Nigeria	Ife Brown			1.3	3.9			Kayode, 1990
	various			2.1	2.8			Fox *ea*, 1977
	various			1.9	2.6			Fox *ea*, 1977
	IVu76			1.5	2.3			Evans *ea*, 1977
	IVu201			1.1	2.5			Evans *ea*, 1977
	Sitao Pole			1.6	3.2			Evans *ea*, 1977
	37 var.			1.6	2.5			Evans & Boulter, 1974
Senegal	various			0.5	2.6			Jacquinot, 1967
Sodium								
Senegal			1.8					Richard *ea*, 1989
USA				0.3	0.3			Warrag & Hall, 1984
				0.2	0.2			Labanauskas *ea*, 1981

With respect to the data in Table 12.4, the following remarks may be made. As the nutrient concentrations in cowpea varieties vary considerably (e.g. Jacquinot, 1967) and the variety of cowpea grown in the Fifth Region in Mali is unknown, the minimum values have been adopted arbitrarily. In addition, as the K-concentration of the various plant organs always exceeds that of groundnut, the minimum K-concentration has been set at twice that of groundnut.

12.3 Three quadrant figures

12.3.1 Phosphorus

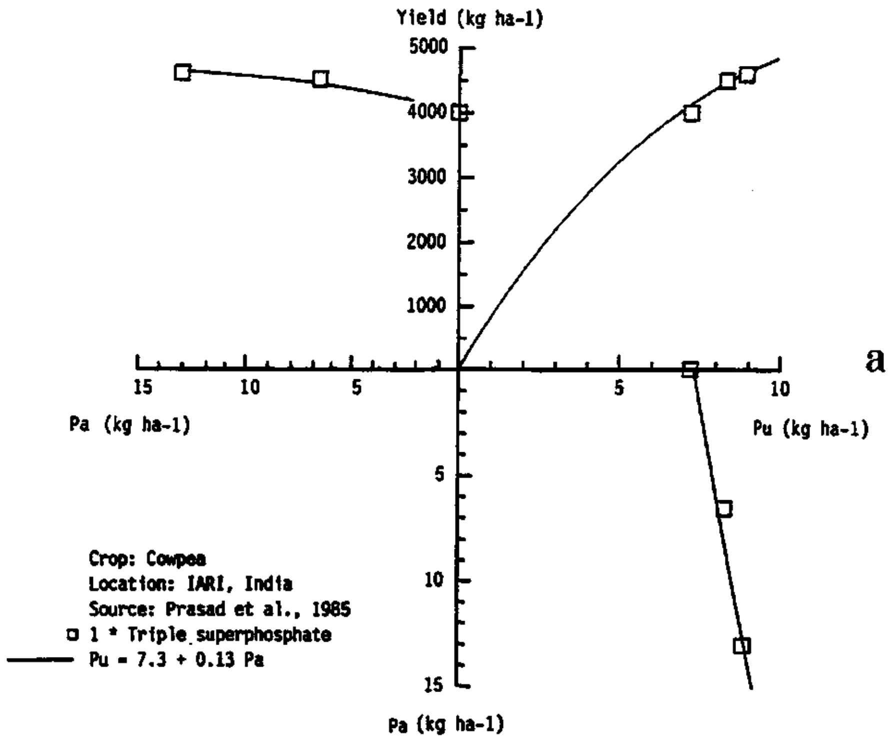


Figure 12.2. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*

12.3.2 Sulphur

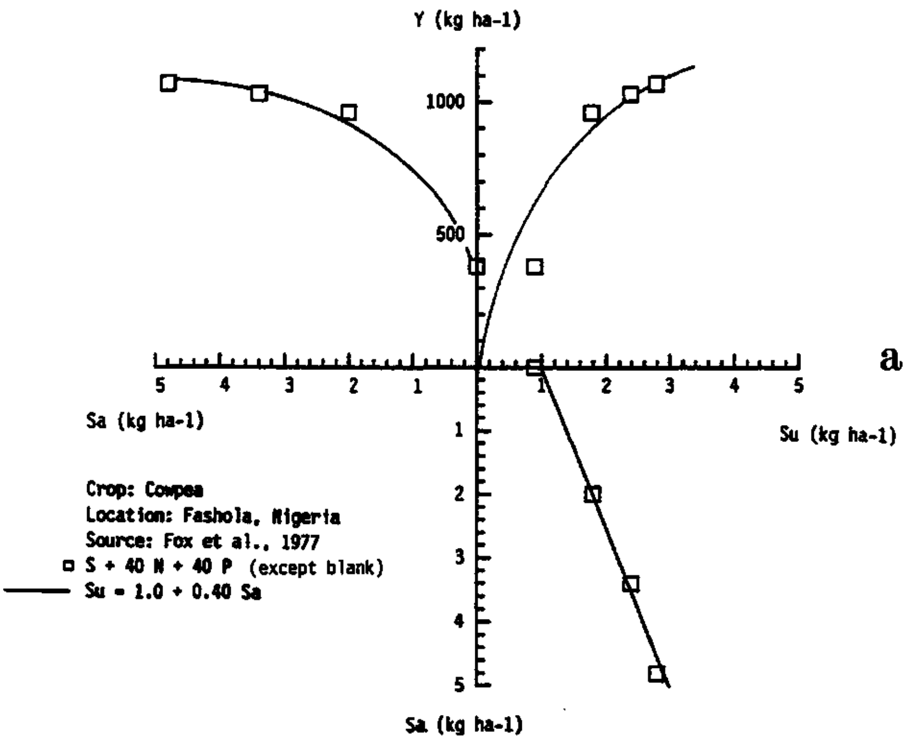


Figure 12.3. *Relation between total sulphur content (S_u) and yield (Y), that between sulphur application (S_a) and sulphur content, and that between sulphur application and yield.*

12.4 Nutrient content as related to yield

The relation yield/N-content is illustrated in Figure 12.4. The nitrogen sources have been quantified in Table 12.5. For phosphorus, the relation yield/content is illustrated in Figure 12.5. The relation total aboveground biomass/K-content is presented in Figure 12.6.

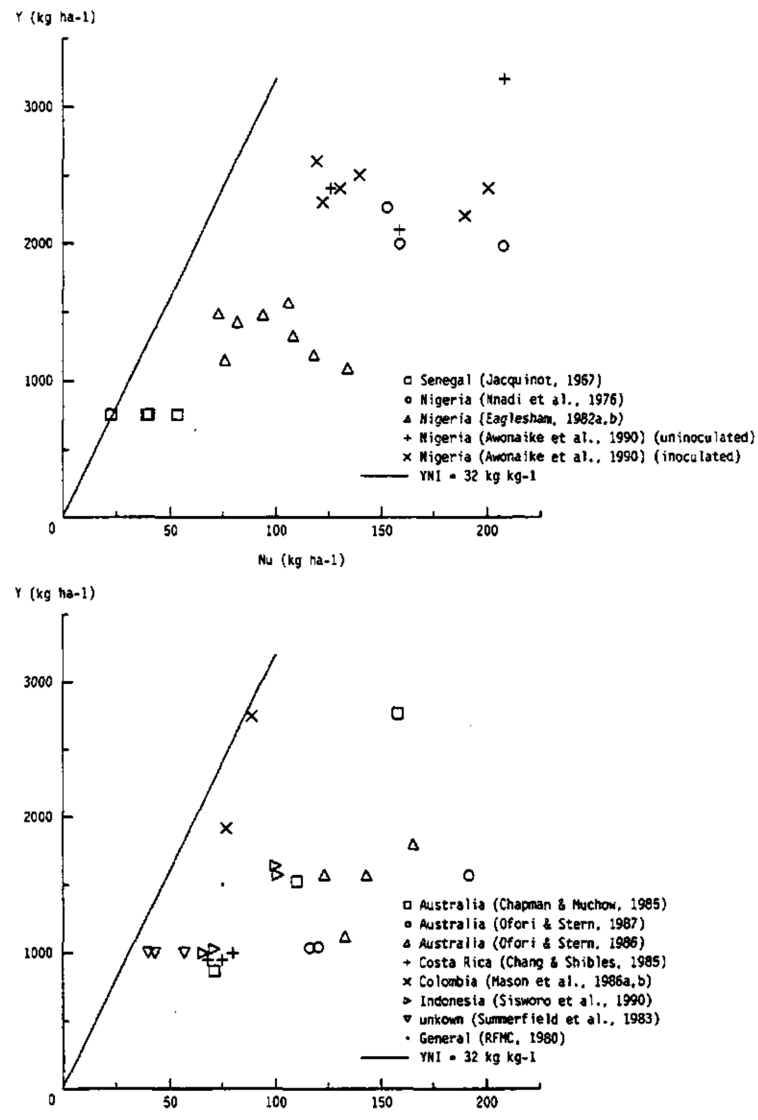


***Figure 12.4.** Relation between total nitrogen content (N_u) and yield (Y) of cowpea a) in West Africa and b) elsewhere; YNI = initial slope.*

Table 12.5. *Total dry matter production and nitrogen content (kg ha^{-1}) of cowpea and its N-sources (%) by fixation (Fix) from fertilizer (Fert) and soil. • = unknown (ea = et al.).*

DMtot	DMgrain	Nu	Fix	Fert	Soil	Country	Source
6 300	2 700	60				Nigeria	Awonaike *ea*, 1990
6 100	2 400	56				Nigeria	Awonaike *ea*, 1990
5 700	2 400	66				Nigeria	Awonaike *ea*, 1990
•	1 430	82	61			Nigeria	Eaglesham *ea*,
•	1 090	134	75			Nigeria	1982b
•	1 570	106	76			Nigeria	Eaglesham *ea*,
•	1 150	76	64			Nigeria	1982b
•	1 480	94	30			Nigeria	Eaglesham *ea*,
•	1 190	118	42			Nigeria	1982b
•	1 330	108	41			Nigeria	Eaglesham *ea*,
•	1 490	73	26			Nigeria	1982b
5 700	•	29	48	9	43	India	Bayopadhyay & De, 1986
				34		UK	Huxley, 1980
•	•	•	12			Indonesia	Sisworo *ea*, 1990
•	•	•	14			Indonesia	Sisworo *ea*, 1990
•	•	•	20			Indonesia	Sisworo *ea*, 1990
•	•	•	33			Indonesia	Sisworo *ea*, 1990
USED			70				

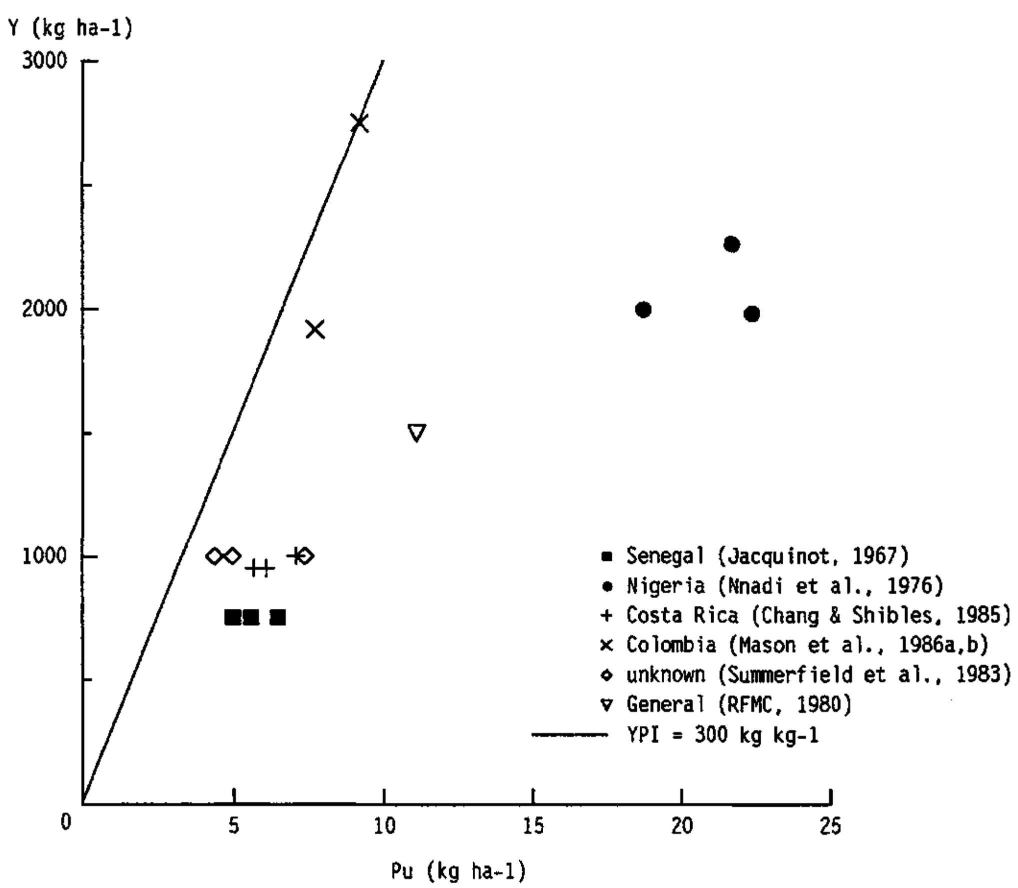


Figure 12.5. Relation between total phosphorus content (P_u) and yield (Y) of cowpea; YPI = initial slope.

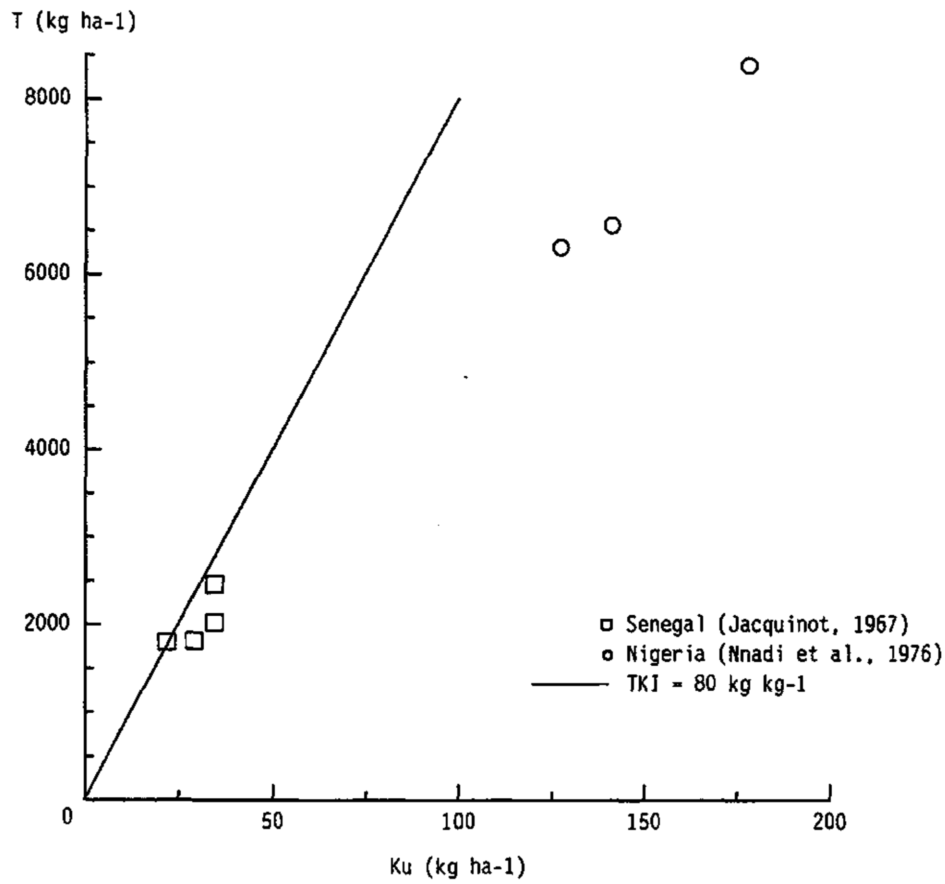


Figure 12.6. *Relation between total potassium content (K_u) and total aboveground dry matter (T) of cowpea; TKI = initial slope.*

12.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 12.7; the P/N of 0.10 is given as comparison with the optimum value in annual grasses (Penning de Vries *et al.*, 1980).

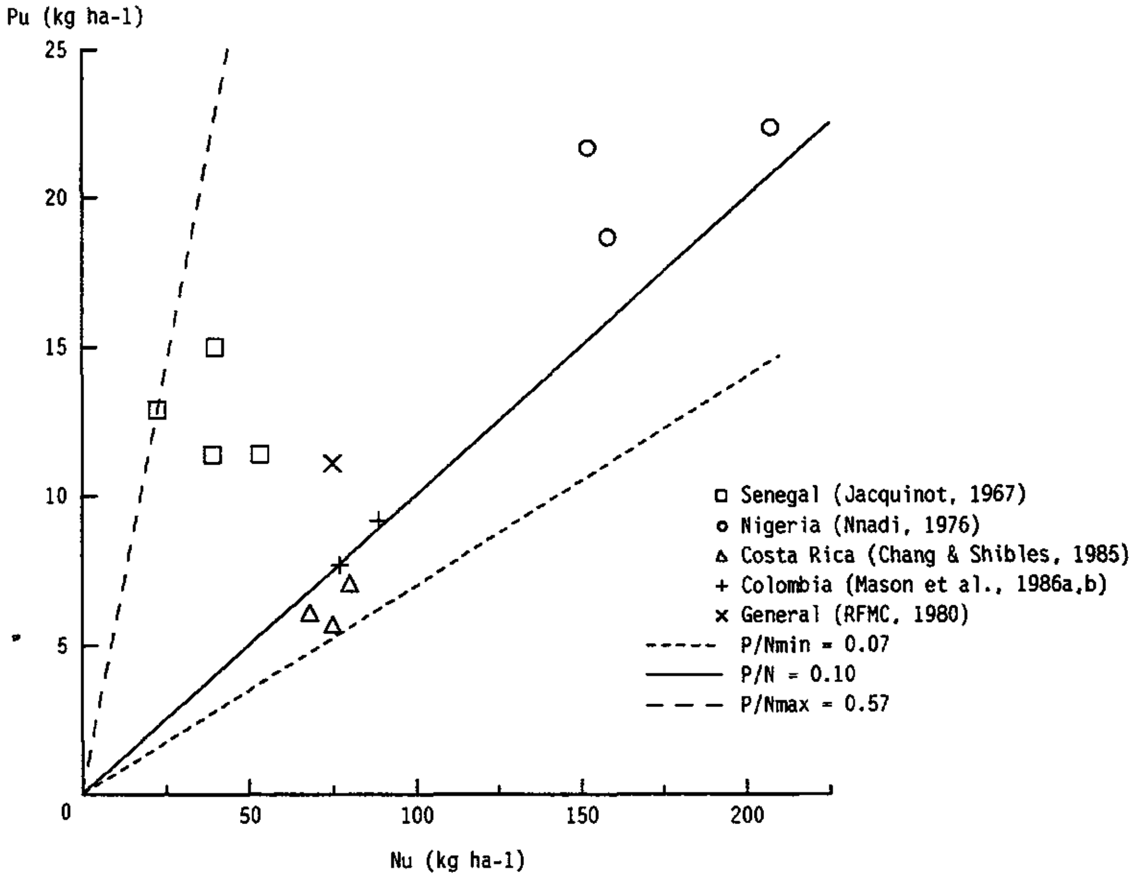


Figure 12.7. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of cowpea in West Africa.*

13. BAMBARA GROUNDNUT

Bambara groundnut is not a major crop in the Fifth Region of Mali, but as it has a high monetary value is may form a good alternative crop.

13.1 Dry matter distribution

Results on dry matter distribution are presented, due to limited data, only as fruit harvest indices (FHI, Table 13.1) and grain fruit ratios (GFR, Table 13.3).

Table 13.1. *Average fruit-harvest indices (FHI, (grain+podshells)/total aboveground biomass) and their range in bambara groundnut. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	FHI	range	n	REMARKS	SOURCE
Mali	0.18	0.05-0.28	7	7 var.	Hulet, 1983
Nigeria	0.49		1		Nnadi *ea*, 1976

Table 13.2. *Grain-fruit ratio (GFR = grains/(grains+podshells)) of bambara groundnut. n: number of observations; each line corresponds to one data set.*

COUNTRY	GFR	range	n	REMARKS	SOURCE
General	0.67		1		Purseglove, 1974

13.2 Concentration of major elements

Table 13.3. *Minimum and maximum concentrations [g kg^{-1}] of major elements in stover, grains and podshells of bambara groundnut; each line corresponds to one dataset (ea = et al.).*

COUNTRY	REMARKS	STRAW min	STRAW max	GRAINS min	GRAINS max	PODSHELLS min	PODSHELLS max	SOURCE
Nitrogen								
Nigeria		19.0		39.4				Nnadi *ea*, 1976
General				34.1				Göhl, 1982
				25.6	33.6			Purseglove, 1974
Phosphorus								
Nigeria		1.1		5.5				Nnadi *ea*, 1976
General				3.0				Göhl, 1982
Potassium								
Nigeria		11.0		15.7				Nnadi *ea*, 1976
Calcium								
Nigeria		25.9		0.7				Nnadi *ea*, 1976
General				0.1				Göhl, 1982
Magnesium								
Nigeria		4.9		1.8				Nnadi *ea*, 1976

14. COTTON

Although cotton has not been distinguished as a separate crop for the Fifth Region of Mali, cotton has been included in this study for the purpose of future elaboration to other regions. However, due to time restrictions, literature has less been investigated.

14.1 Dry matter distribution

Table 14.1. *Average harvest indices (seeds/total aboveground biomass) and their range in cotton. n: number of observations; each line corresponds to one data set (ea = et al.).*

COUNTRY	HI	range	n	REMARKS	SOURCE
Benin	0.37		1		Déat *ea*, 1976
Cameroun	0.36	0.33-0.38	3	1975	Gigou, 1986a
	0.33	0.32-0.34	3	1977	Gigou, 1986a
	0.19	0.17-0.24	5		Dubernard quoted by Poulain, 1980
	0.40	0.39-0.41	2		Déat *ea*, 1976
Ivory Coast	0.25	0.19-0.29	3		Poulain, 1980
	0.51	0.49-0.54	6	1988	Chopart, 1989
	0.51	0.50-0.52	6	1988	Chopart, 1989
	0.36	0.32-0.40	2		Déat *ea*, 1976
Nigeria	0.40		1		Balasubramanian & Nnadi, 1981
Turkey	0.61	0.59-0.64	9		Atanasiu ea, 1978b

14.2 Concentration of major elements

With respect to the data in Table 14.2, the following remarks may be made. The lowest nutrient concentrations reported by Déat *et al.* (1976) seems too low in comparison with other data, hence the nearest lowest values have been adopted.

Table 14.2. *Minimum and maximum concentrations (g kg^{-1}) of major elements in stover (stalks and leaves) and seeds (including lint) of cotton; each line corresponds to one dataset (ea = et al.).*

COUNTRY REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Nitrogen							
Benin	7.3	9.4	23.3	40.5			Déat *ea*, 1976
Cameroon	13.1	15.4					Dubernard quoted by Poulain, 1981
	7.7	9.5	29.8	30.5			Déat *ea*, 1976
	15.2	17.8					Déat *ea*, 1976
Cameroon, Benin	8.3		27.4				Déat *ea*, 1976
Ivory Coast			32.4				Déat *ea*, 1976
	6.0	7.9	15.8	37.2			Déat *ea*, 1976
Nigeria	13.3						Balasubramanian & Nnadi, 1981
	12.8						Okaiyeto, 1984
Senegal				28.0			Tourte *ea*, 1971
General			40.0				Sinclair & de Wit, 1975
Phosphorus							
Benin	0.9	1.1	4.1	5.3			Déat *ea*, 1976
Cameroon	1.6	2.2					Dubernard quoted by Poulain, 1981
	1.8	2.1	6.1	6.5			Déat *ea*, 1976
	1.6	2.2					Déat *ea*, 1976
Cameroon, IC, Benin	1.2		4.7				Déat *ea*, 1976
Ivory Coast			4.5				Déat *ea*, 1976
	0.6	1.2	2.9	4.2			Déat *ea*, 1976
Nigeria	2.7						Balasubramanian & Nnadi, 1981
Senegal				4.8			Tourte *ea*, 1971
Potassium							
Benin	7.7	10.1	9.7	11.6			Déat *ea*, 1976
Cameroon	12.8	17.2					Dubernard quoted by Poulain, 1981
	15.0	26.8	12.8	13.1			Déat *ea*, 1976
	13.6	15.6					Déat *ea*, 1976
Cameroon, IC, Benin	12.4		11.0				Déat *ea*, 1976
Ivory Coast			10.1				Déat *ea*, 1976
	11.1	19.4	8.2	9.9			Déat *ea*, 1976
Nigeria	23.5						Balasubramanian & Nnadi, 1981
Senegal				10.0			Tourte ea, 1971
Calcium							
Benin	5.7	7.0	1.3	1.8			Déat *ea*, 1976
Cameroon	6.8	8.4					Dubernard quoted by Poulain, 1981
	5.3	6.3	1.3	2.1			Déat *ea*, 1976
	6.8	8.4					Déat *ea*, 1976
Cameroon, IC, Benin	6.0		1.6				Déat *ea*, 1976
Ivory Coast			2.9				Déat *ea*, 1976
	4.6	5.9	1.1	3.6			Déat *ea*, 1976
Nigeria	12.7						Balasubramanian & Nnadi, 198
Senegal				2.1			Tourte *ea*, 1971

.../...

Table 14.2. Continued.

COUNTRY REMARKS	STOVER min	STOVER max	GRAINS min	GRAINS max	TOTAL min	TOTAL max	SOURCE
Magnesium							
Benin	1.1	1.5	3.0	3.7			Déat *ea*, 1976
Cameroon	2.4	2.8					Dubernard quoted by Poulain, 1981
	1.5	2.0	3.2	3.3			Déat *ea*, 1976
	2.8	2.8					Déat *ea*, 1976
Cameroon, IC, Benin	1.7		2.9				Déat *ea*, 1976
Ivory Coast			2.7				Déat *ea*, 1976
	1.2	1.4	1.7	2.8			Déat *ea*, 1976
Nigeria	2.5						Balasubramanian & Nnadi, 1981
Sulphur							
Benin	0.9	1.1	1.9	2.9			Déat *ea*, 1976
Cameroon	1.5	2.0					Dubernard quoted by Poulain, 1981
	2.0	2.3	1.9	2.5			Déat *ea*, 1976
	2.0	2.8					Déat *ea*, 1976
Cameroon, IC, Benin	1.4		2.3				Déat *ea*, 1976
Ivory Coast			2.3				Déat *ea*, 1976
	1.4	1.5	2.4	2.6			Déat *ea*, 1976
Sodium							
Nigeria	13.3						Balasubramanian & Nnadi, 1981

14.3 Three quadrant figures

14.3.1 Phosphorus

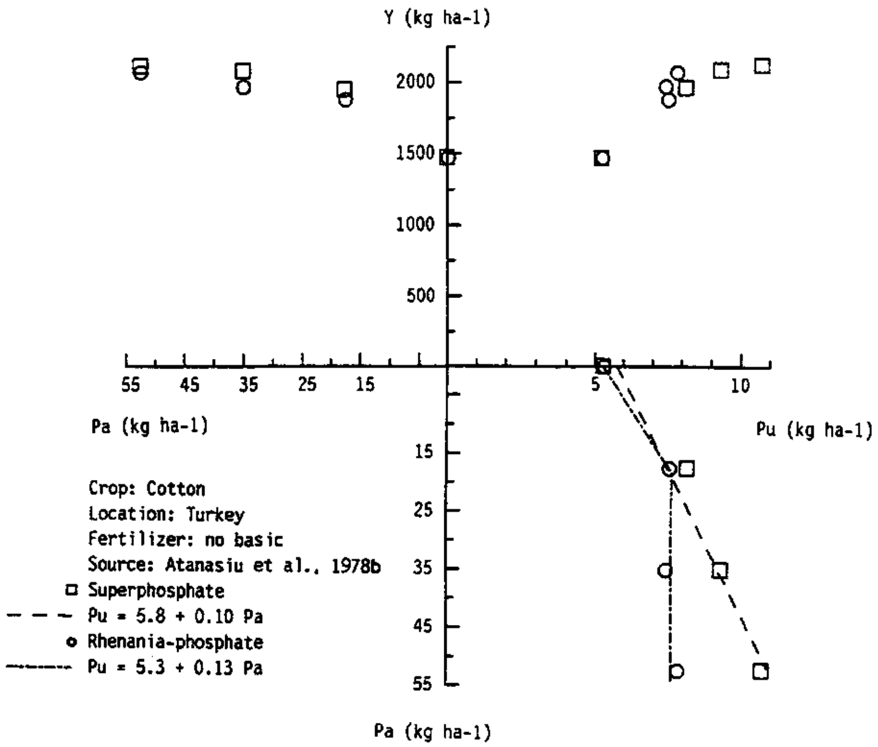


Figure 14.1. *Relation between total phosphorus content (P_u) and yield (Y), that between phosphorus application (P_a) and phosphorus content, and that between phosphorus application and yield.*

14.4 Nutrient content as related to yield

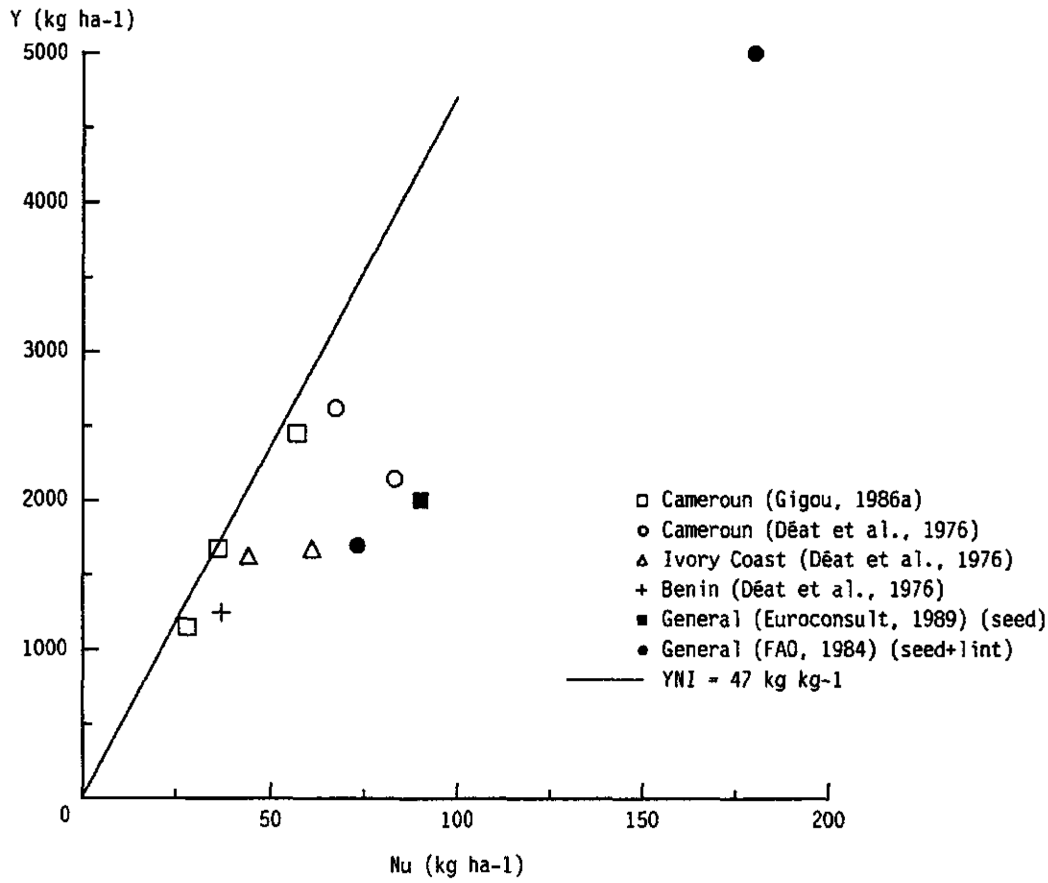


Figure 14.2. *Relation between total nitrogen content (N_u) and yield (Y) of cotton; YNI = initial slope.*

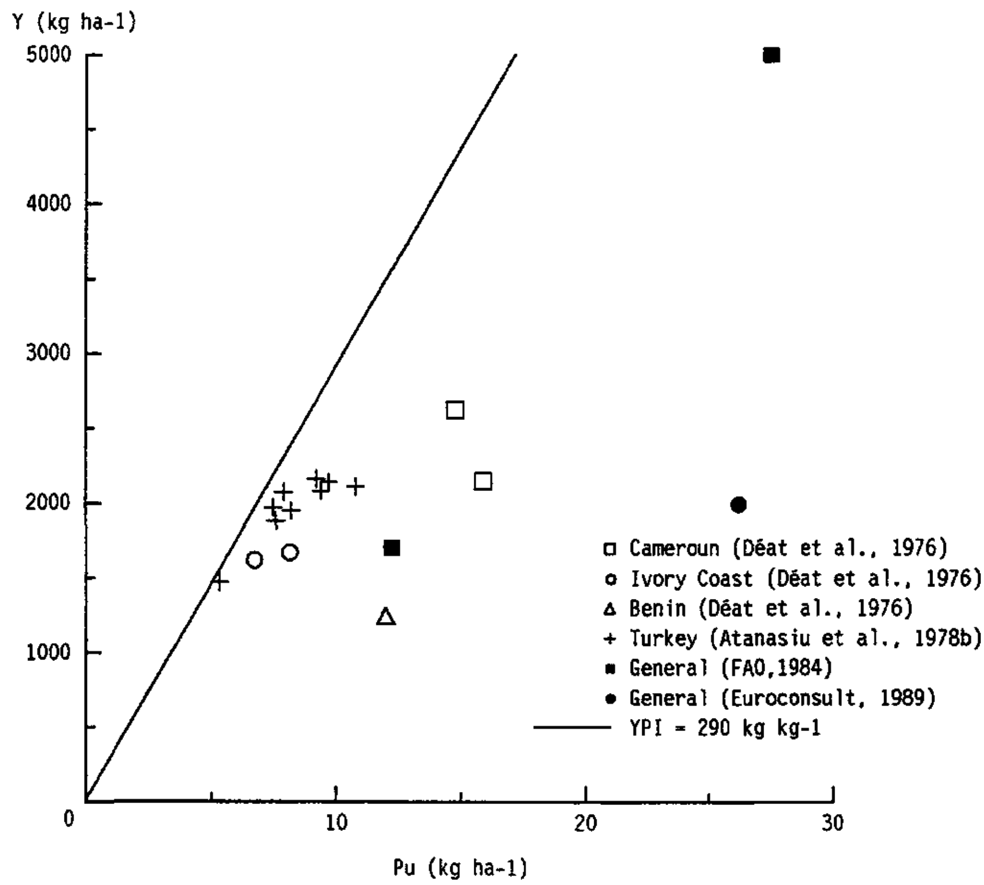


Figure 14.3. *Relation between total phosphorus content (P_u) and yield (Y) of cotton; YPI = initial slope.*

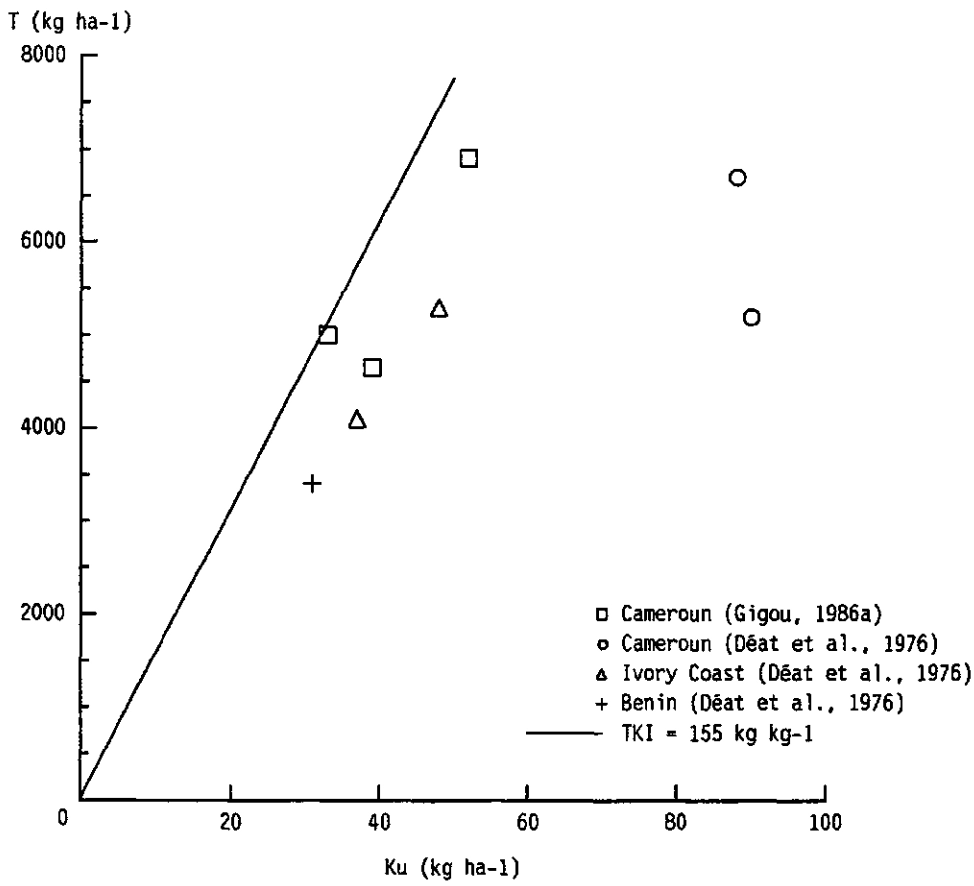


Figure 14.4. *Relation between total potassium content (K_u) and total aboveground dry matter (T) of cotton; TKI = initial slope.*

14.5 Ratio phosphorus content to nitrogen content

Minimum and maximum P/N ratios are graphically presented in Figure 14.5.

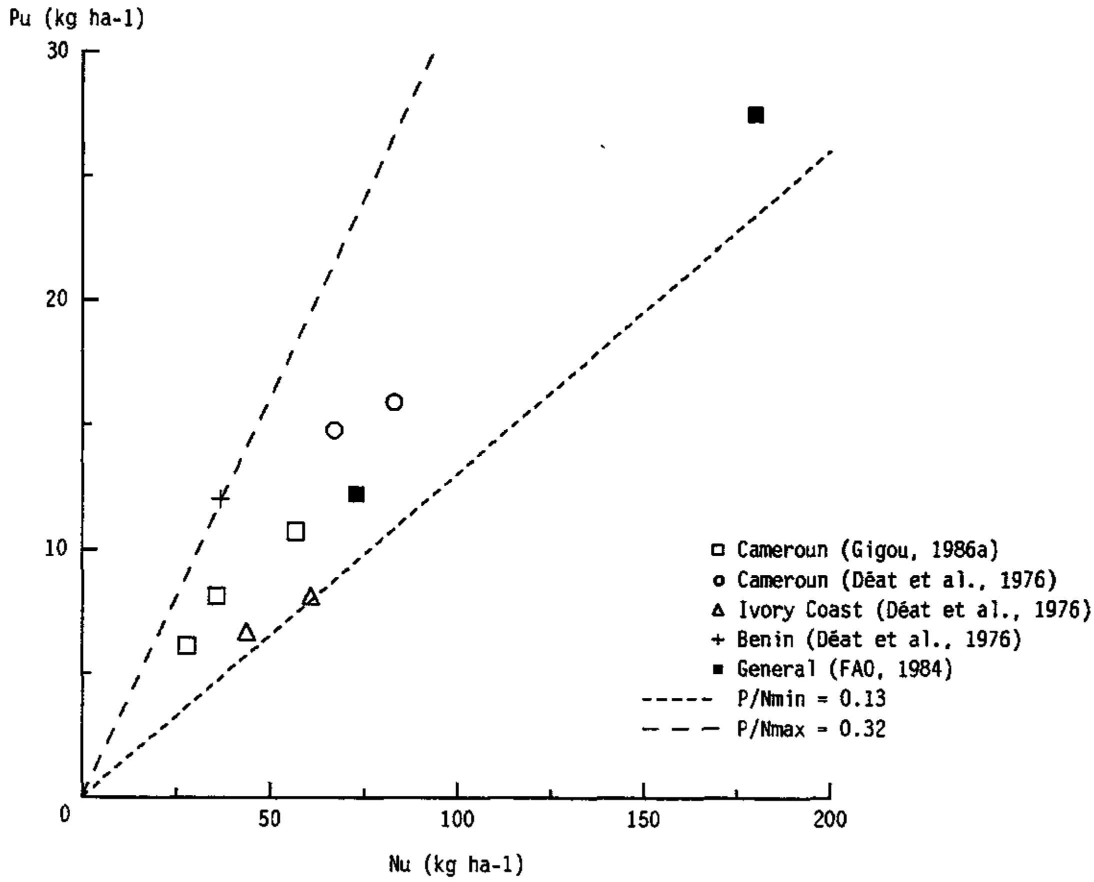


Figure 14.5. *Relation between nitrogen and phosphorus content at maturity in aboveground biomass of cotton.*

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ANNEX 1. RECOVERY FRACTIONS

ANNEX 1. RECOVERY FRACTIONS

Table A1.1. *Nitrogen fertilizer recovery (NFR, kg kg^{-1}) in total above-ground biomass of the various crops, as derived from the constructed figures in Part B or from cited literature.*
P: annual precipitation (mm), irr = irrigated; OM: n = no application of organic matter, man = manure, str = straw;
N_{am}: maximum application level for validity of regression line (kg ha^{-1}) in the figure referred to.
FT: fertilizer type: 1 = urea, 2 = NPK, 3 = NP, 4 = ammonium sulphate, 5 = P-K fertilizer, 6 = Ammonium nitrate;
AT: application time: 1 = at ploughing/after emergence, 2 = as 1 + at anthesis, 3 = 3 times;
ST: Soil type: 1 = sand, 2 = sandy loam, 3 = sandy clay, 4 = clay, 5 = clay-loam; • = unknown.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
MILLET										
Souna	Mali	1982	•	n	0.74	4.3f	150	3	2	•
Souna	Mali	1982	•	n	0.83	4.3f	100	1	2	•
Niou Bobo	Mali	1971	700	n	0.10	4.3a	160	1	2	•
HKN	Niger	1971	339	n	0.28	4.3c	90	1	2	•
P3 Kolo	Niger	1972	283	n	0.17	4.3d	90	1	2	•
P3 Kolo	Niger	1973	296	n	0.56	4.3d	90	1	2	•
HKN	Niger	1971	339	str	0.21	4.3c	90	1	2	•
P3 Kolo	Niger	1972	283	str	0.18	4.3d	90	1	2	•
P3 Kolo	Niger	1973	296	str	0.51	4.3d	45	1	2	•
Gero Hairy	Nigeria	•	•	n	0.53	4.3h	75	•	•	•
Dwarf c.	Nigeria	•	•	n	0.41	4.3h	100	•	•	•
Gero early	Nigeria	•	•	n	0.30	4.3h	75	•	•	•
Hybrid	Nigeria	•	•	n	0.55	4.3h	75	•	•	•
Ex-Bornu	Nigeria	•	•	n	0.52	4.3h	25	•	•	•
HKP	Nigeria	•	•	n	0.14	Reddy *et al.*, 1992				
HKP	Nigeria	•	•	n	0.16	Reddy *et al.*, 1992 (2 times)				
HKP	Nigeria	•	•	n	0.19	Reddy *et al.*, 1992				
HKP	Nigeria	•	•	n	0.27	Reddy *et al.*, 1992				
Souna III	Senegal	1988	917	n	0.15	4.3e	60	1	2	1
Souna III	Senegal	1973	•	n	0.33	4.3b	150	1	3	1
•	Senegal	•	•	n	0.55	4.3g	48	•	•	•
Souna III	Senegal	1988	917	man	0.55	4.3e	60	1	2	1
Souna III	Senegal	1973	•	str	0.27	4.3b	150	1	2	1
Syn.1	Senegal	•	•	n	0.56	Ganry, 1990				
Syn.1	Senegal	•	•	man	0.90	Ganry, 1990				
Bajra	India	1970	•	•	0.42	Lal, 1979				
Bajra	India	1971	•	•	0.44	Lal, 1979				
BK560	India	75-76	irr	•	0.21	Munda *et al.*, 1984				
HB1	India	•	•	•	0.52	Singh & Randhawa, 1979				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
SORGHUM										
S29	Burkina	•	•	n	0.30	5.3b	100	2	•	•
	Burkina	•	•	man	1.05	5.3b	100	2	•	•
IRAT55	Cameroun	1976	704	n	0.64	5.3a	78	4	2	•
•	Senegal	1968	•	•	0.22	5.3f	139	•	•	•
•	Senegal	1968	•	•	0.74	5.3f	49	•	•	•
Dekalb	Australia	•	irr	n	0.35	5.3e	250	•	•	•
DK55	Australia	•	irr	n	0.32	5.3e	250	•	•	•
Dekalb	Australia	•	irr	n	0.48	5.3e	80	•	•	•
Dekalb	Australia	•	irr	n	0.33	5.3e	250	•	•	•
Pioneer846	Australia	70-71	•	•	0.31	Myers, 1978a				
Pioneer846	Australia	70-71	•	•	0.31	Myers, 1978a				
Texas610SR	Australia	1981	irr	n	0.52	Wright *et al.*, 1985				
Texas610SR	Australia	1981	irr	n	0.18	Wright *et al.*, 1985				
•	Australia	1986	irr	n	0.35	Muchow, 1988				
CSH-I	India	•	•	n	0.49	5.3c	120	•	2	•
CSH-I	India	•	•	n	0.55	5.3c	120	3	2	•
Um Benein	India	1959	•	n	0.14	Rai, 1965b				
Um Benein	India	1959	•	n	0.19	Rai, 1965b				
Um Benein	India	1960	•	n	0.54	Rai, 1965b				
Um Benein	India	1960	•	n	0.34	Rai, 1965b				
Um Benein	India	1961	•	n	0.36	Rai, 1965b				
Um Benein	India	1961	•	n	0.45	Rai, 1965b				
•	India	67-68	•	n	0.40	Singh & Bains, 1973				
RS671	Puer.Rico	1970	•	n	0.05	Fox *et al.*, 1974				
RS671	Puer.Rico	1970	•	n	0.24	Fox *et al.*, 1974				
RS671	Puer.Rico	1970	•	n	0.24	Fox *et al.*, 1974				
RS671	Puer.Rico	1970	•	n	0.19	Fox *et al.*, 1974				
Wad Aker	Sudan	1961	.	n	0.31	5.3d	170	•	•	•
Wad Aker	Sudan	1961	.	n	0.47	5.3d	170	•	•	•
GT 350	USA	1983	•	n	0.05	Lafitte & Loomis, 1988				
NC70x	USA	1972	•	n	0.27	Perry & Olson, 1975				
NC70x	USA	1972	•	n	0.33	Perry & Olson, 1975				
NC70x	USA	1972	•	n	0.32	Perry & Olson, 1975				
NC70x	USA	1972	•	n	0.37	Perry & Olson, 1975				
RS671	USA	1973	•	n	0.35	Perry & Olson, 1975				
RS671	USA	1973	•	n	0.27	Perry & Olson, 1975				
RS671	USA	1973	•	n	0.51	Perry & Olson, 1975				
RS671	USA	1973	•	n	0.37	Perry & Olson, 1975				
MAIZE										
local	Burkina	1963	•	n	0.29	Dupont de Dinechin, 1968				
Tiémantié	Mali	1971	•	n	0.44	6.2b	190	1	2	•
TZAxTZB	Nigeria	•	•		0.90	6.2a	120	1+5	•	•
TZAxTZB	Nigeria	•	•		0.81	6.2a	120	1+5	•	•
No3	Nigeria	1969	920	n	0.75	6.2c	137	6	•	2
No3	Nigeria	1971	691	n	0.41	6.2c	230	6	•	2
•	Nigeria	1976	•	n	0.70	6.2f	180	1	•	•
•	Australia	1986	irr	n	0.40	Muchow, 1988				
•	Australia		•	n	0.77	Ofori & Stern, 1986 (intercrop)				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
MAIZE										
XL 66	Australia	83-84	•	n	1.44	Ofori & Stern, 1987				
Aladin	Belgium	1990	•	n	0.42	Eeckhaut & Behaeghe, 1991				
Aladin	Belgium	1990	•	n	0.20	Eeckhaut & Behaeghe, 1991				
Cargill111	Brazil	73-78	•	•	0.29	Grove *et al.*, 1980				
Cargill111	Brazil	73-78	•	•	0.34	Grove *et al.*, 1980				
Vijay	India	1971	•	n	0.32	6.2e	150	1	•	2
Vijay	India	1971	•	n	0.33	6.2e	150	4	•	2
Vijay	India	1971	•	n	0.46	6.2e	150	6	•	2
Vijay	India	1971	•	n	0.37	6.2e	150	6	•	2
•	India	75-77	•	•	0.61	Ahlawat *et al.*, 1981				
•	India	1960	•	n	0.08	Rai, 1965b				
•	India	1961	•	n	0.48	Rai, 1965b				
•	India	1972	•	•	0.72	Kapur & Sekhon, 1977 (+ P, K)				
local	India	1974	•	n	0.61	Dass & Singh, 1979				
local	India	1975	•	n	0.46	Dass & Singh, 1979				
local	India	1974	•	n	0.23	Dass & Singh, 1979				
Ganga 5	India	84-86	•	n	0.28	Verma & Singh, 1991				
various	Italy	78-79	•	n	0.58	di Fonzo *et al.*, 1982				
Px610	N.Zealand	1972	•	•	0.18	Thom & Watkin, 1978				
Px306	Puer.Rico	1970	•	n	0.24	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.31	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.20	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.04	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.55	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.21	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.43	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.37	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.57	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.37	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.19	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.19	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.05	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.32	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.16	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.26	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.11	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.33	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.43	Fox *et al.*, 1974				
Px306	Puer.Rico	1970	•	n	0.48	Fox *et al.*, 1974				
Mexican	Sudan	1961	•	n	0.47	6.2d	171	4	4	1
June	Sudan	1961	•	n	0.50	6.2d	171	4	4	1
Mexican	Sudan	1961	•	n	0.14	6.2d	171	4	4	1
June	Sudan	1961	•	n	0.20	6.2d	171	4	4	1
•	USA	1978	•	•	0.22	Anderson *et al.*, 1984b				
•	USA	1978	•	•	0.36	Anderson *et al.*, 1984b				
SX 19	USA	1976	•	•	0.39	Bigeriego *et al.*, 1979				
SX 19	USA	1976	•	•	0.51	Bigeriego *et al.*, 1979				
Dixie 11	USA	1946	•	•	0.62	Jordan *et al.*, 1950				
Dixie 11	USA	1946	•	•	0.73	Jordan *et al.*, 1950				
Pioneer	USA	1983	•	n	0.25	Mackay & Barber, 1986				
Pioneer	USA	1983	•	n	0.33	Mackay & Barber, 1986				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
MAIZE										
•	USA	1978	•	n	0.14	Moll *et al.*, 1982				
•	USA	1978	•	n	0.32	Moll *et al.*, 1982				
•	USA	1978	•	n	0.28	Moll *et al.*, 1982				
•	USA	1978	•	n	0.20	Moll *et al.*, 1982				
•	USA	1978	•	n	0.00	Moll *et al.*, 1982				
•	USA	1978	•	n	0.33	Moll *et al.*, 1982				
•	USA	1978	•	n	0.10	Moll *et al.*, 1982				
•	USA	1978	•	n	0.18	Moll *et al.*, 1982				
Neb714	USA	1979	•	n	0.11	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.06	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.08	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.00	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.22	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.28	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.27	Russelle *et al.*, 1983				
Neb714	USA	1979	•	n	0.17	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.47	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.43	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.39	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.38	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.30	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.33	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.67	Russelle *et al.*, 1983				
Neb714	USA	1980	•	n	0.67	Russelle *et al.*, 1983				
P 3306	USA	1972	•	n	0.41	Perry & Olson, 1975				
P 3306	USA	1972	•	n	0.39	Perry & Olson, 1975				
P 3306	USA	1972	•	n	0.46	Perry & Olson, 1975				
P 3306	USA	1972	•	n	0.48	Perry & Olson, 1975				
Nebraska	USA	1973	•	n	0.34	Perry & Olson, 1975				
Nebraska	USA	1973	•	n	0.36	Perry & Olson, 1975				
Nebraska	USA	1973	•	n	0.39	Perry & Olson, 1975				
Nebraska	USA	1973	•	n	0.29	Perry & Olson, 1975				
Rice										
IDSA6	Ivory C.	1989	•	n	0.10	7.2i	50	1+5	•	•
IDSA6	Ivory C.	1989	•	n	0.40	7.2i	50	1+5	•	•
IDSA6	Ivory C.	1989	•	n	0.06	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.25	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.01	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.00	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.20	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.52	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.54	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.35	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.26	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.31	Koopmans, 1990 (+P fert.)				
•	Ivory C.	•	•	n	0.41	7.2j	120	•	•	•
IR8	Mali	1971	•	n	0.48	7.2a	120	1	2	•
BG79	Nigeria	58-61	•	n	0.17	7.2c	100	4	•	4
BG79	Nigeria	58-61	•	n	0.17	7.2c	100	4+3	•	4
BG79	Nigeria	58-61	•	n	0.19	7.2c	100	4+3	•	4

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
RICE										
BG79	Nigeria	58-61	•	n	0.12	7.2d	150	4	•	1
BG79	Nigeria	58-61	•	n	0.08	7.2d	150	4+3	•	1
BG79	Nigeria	58-61	•	n	0.08	7.2d	150	4+3	•	1
IR8	Senegal	1968	•	n	0.56	7.2b	200	1	•	•
IR8	Senegal	1968	•	n	0.62	7.2b	200	3	•	•
IR8	Senegal	1968	•	n	0.54	7.2b	200	1+3	•	•
IKP	Senegal	•	•	n	0.17	7.2e	70	4	2	•
IKP	Senegal	•	•	n	0.38	7.2e	80	4	2	•
IKP	Senegal	1970	•	n	0.59	7.2g	110	2+4	2	•
IKP	Senegal	1970	•	n	0.27	7.2g	110	2+4	2	•
IKP	Senegal	1970	•	n	0.17	7.2g	80	2+4	2	•
IKP	Senegal	1971	•	n	0.23	7.2h	60	2+4	2	•
IKP	Senegal	1971	•	n	0.25	7.2h	120	2+4	2	•
IR8	Australia	•	•	n	0.70	7.2f	270	4	•	1
•	Australia	1981	•	n	0.87	Humphreys *et al.*, 1987				
•	Australia	1981	•	n	0.62	Humphreys *et al.*, 1987				
•	Australia	1981	•	n	0.44	Humphreys *et al.*, 1987				
•	Australia	1981	•	n	0.12	Humphreys *et al.*, 1987				
•	Australia	•	•	•	0.36	van Keulen, 1977				
•	Australia	•	•	•	0.52	van Keulen, 1977				
•	Australia	•	•	•	0.40	van Keulen, 1977				
•	Australia	•	•	•	0.44	van Keulen, 1977				
•	Bangladesh	1982	•	•	0.24	van Keulen & de Wit, 1984				
•	Bangladesh	1982	•	•	0.15	van Keulen & de Wit, 1984				
•	Bangladesh	1982	•	•	0.33	van Keulen & de Wit, 1984				
•	Burma	•	•	•	0.20	van Keulen, 1977				
•	Burma	•	•	•	0.22	van Keulen, 1977				
•	Burma	•	•	•	0.15	van Keulen & van Heemst, '82				
•	Burma	•	•	•	0.14	van Keulen & van Heemst, '82				
Weiyou35	China	1988	•	n	0.16	Jun *et al.*, 1991				
Padma, Bala	India	1972	•	n	0.22	7.2k	120	1	1	5
Padma, Bala	India	1973	•	n	0.28	7.2k	120	1	1	5
C10754	India	1976	•	n	0.21	Bhushan & Singh, 1979				
dwarf	India	•	•	•	0.38	van Keulen, 1977				
dwarf	India	•	•	•	0.55	van Keulen, 1977				
Dular	India	•	•	•	0.35	van Keulen, 1977				
•	India	1966	•	n	0.54	Mahapatra & Pande, 1972				
•	India	1966	•	n	0.39	Mahapatra & Pande, 1972				
•	India	1967	•	n	0.36	Mahapatra & Pande, 1972				
Raghusail	India	1964	•	n	0.18	Majumdar, 1973				
Raghusail	India	1965	•	n	0.24	Majumdar, 1973				
•	India	•	•	•	0.50	Mehrotra *et al.*, 1968 (- P)				
•	India	•	•	•	0.59	Mehrotra *et al.*, 1968 (+ P)				
•	India	•	•	•	0.65	Mehrotra *et al.*, 1968 (+ P)				
Ratna	India	1981	•	n	0.24	Singh & Singh, 1987				
Ratna	India	1981	•	n	0.71	Singh & Singh, 1987(+Azolla)				
Ratna	India	1982	•	n	0.34	Singh & Singh, 1987				
Ratna	India	1982	•	n	0.80	Singh & Singh, 1987(+Azolla)				
Ratna	India	1982	•	n	0.44	Singh & Singh, 1987				
Ratna	India	1982	•	n	1.05	Singh & Singh, 1987(+Azolla)				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
RICE										
Ratna	India	1985	•	man	0.21	Sharma & Mittra, 1991				
IR20	India	1985	•	man	0.37	Sharma & Mittra, 1991				
IR64	Indonesia	1990	•	•	0.21	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.25	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.22	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.24	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.42	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.46	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.28	Daradjat *et al.*, 1991				
IR64	Indonesia	1990	•	•	0.41	Daradjat *et al.*, 1991				
IR5	Indonesia	•	•	•	0.30	van Keulen, 1977				
IR5	Indonesia	•	•	•	0.40	van Keulen, 1977				
IR5	Indonesia	•	•	•	0.48	van Keulen, 1977				
IR5	Indonesia	•	•	•	0.49	van Keulen, 1977				
IR5	Indonesia	•	•	•	0.46	van Keulen, 1977				
IR26	Indonesia	•	•	•	0.51	van Keulen, 1977				
IR5	Indonesia	•	•	•	0.31	van Keulen, 1977				
IR26	Indonesia	•	•	•	0.56	van Keulen, 1977				
IR26	Indonesia	•	•	•	0.27	van Keulen, 1977				
•	Indonesia	•	•	•	0.35	van Keulen, 1977				
IR64	Indonesia	89-90	•	•	0.57	Makarim *et al.*, 1991				
•	Japan	•	•	•	0.44	van Keulen, 1977				
•	Japan	•	•	•	0.58	de Datta, 1981				
•	Peru	•	•	•	0.53	van Keulen & van Heemst, '82				
IR36	Phillipines	1983	•	n	0.95	De Datta, 1985				
•	Phillipines	•	•	•	0.48	van Keulen, 1977				
•	Phillipines	•	•	•	0.39	van Keulen, 1977				
•	Phillipines	•	•	•	0.26	van Keulen, 1982				
•	Phillipines	•	•	•	0.36	van Keulen, 1982				
Tongil	Phillipines	•	•	•	0.52	van Keulen, 1977				
Tongil	Phillipines	•	•	•	0.51	van Keulen, 1977				
Tongil	Phillipines	•	•	•	0.41	van Keulen, 1977				
Bg 11-11	Shri Lanka	•	•	•	0.31	van Keulen, 1977				
Bg 11-11	Shri Lanka	•	•	•	0.51	van Keulen, 1977				
Bg 34-8	Shri Lanka	•	•	•	0.49	van Keulen, 1977				
Bg 34-8	Shri Lanka	•	•	•	0.73	van Keulen, 1977				
Pb 76-63	Thailand	•	•	•	0.29	van Keulen, 1977				
Pb 76-63	Thailand	•	•	•	0.47	van Keulen, 1977				
•	USA	•	•	•	0.12	van Keulen, 1977				
•	USA	•	•	•	0.18	van Keulen, 1977				
•	USA	•	•	•	0.33	van Keulen, 1977				
•	USA	•	•	•	0.46	van Keulen, 1982				
•	USA	•	•	•	0.40	van Keulen, 1982				
Vesta	USA	1974	•	•	0.67	Reddy & Patrick, 1976				
Vesta	USA	1974	•	•	0.52	Reddy & Patrick, 1976				
Vesta	USA	1974	•	•	0.60	Reddy & Patrick, 1976				
Vesta	USA	1974	•	•	0.47	Reddy & Patrick, 1976				
Vesta	USA	1975	•	•	0.52	Reddy & Patrick, 1976				
Vesta	USA	1975	•	•	0.44	Reddy & Patrick, 1976				
Vesta	USA	1975	•	•	0.47	Reddy & Patrick, 1976				
Vesta	USA	1975	•	•	0.43	Reddy & Patrick, 1976				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
RICE										
Vesta	USA	1975	•	•	0.32	Reddy & Patrick, 1978				
Vesta	USA	1975	•	•	0.41	Reddy & Patrick, 1978				
Vesta	USA	1975	•	•	0.46	Reddy & Patrick, 1978				
Vesta	USA	1975	•	•	0.50	Reddy & Patrick, 1978				
Vesta	USA	1976	•	•	0.69	Reddy & Patrick, 1978				
Vesta	USA	1976	•	•	0.73	Reddy & Patrick, 1978				
Vesta	USA	1976	•	•	0.54	Reddy & Patrick, 1978				
Vesta	USA	1976	•	•	0.78	Reddy & Patrick, 1978				
•	USA	•	•	•	0.87	Sims & Place, 1968				
DEEP WATER RICE										
HTA60	Thailand	1986	•	n	0.00	Puckridge *ea.*,1991(2 times)				
HTA60	Thailand	1986	•	n	0.03	Puckridge *et al.*, 1991				
HTA60	Thailand	1986	•	n	0.17	Puckridge *et al.*, 1991				
HTA60	Thailand	1986	•	n	0.31	Puckridge *et al.*, 1991				
HTA60	Thailand	1986	•	n	0.39	Puckridge *et al.*, 1991				
HTA60	Thailand	1986	•	n	0.57	Puckridge *et al.*, 1991				
HTA60	Thailand	1987	•	n	0.00	Puckridge *ea*, 1991(4 times)				
HTA60	Thailand	1987	•	n	0.16	Puckridge *et al.*, 1991				
HTA60	Thailand	1987	•	n	0.41	Puckridge *et al.*, 1991				
HTA60	Thailand	1987	•	n	0.55	Puckridge *et al.*, 1991				
HTA60	Thailand	1988	•	n	0.22	Puckridge *et al.*, 1991				
HTA60	Thailand	1988	•	n	0.28	Puckridge *et al.*, 1991				
HTA60	Thailand	1988	•	n	0.36	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.31	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.39	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.45	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.51	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.58	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.61	Puckridge *et al.*, 1991				
RD19	Thailand	1986	•	n	0.79	Puckridge *et al.*, 1991				
RD19	Thailand	1987	•	n	0.14	Puckridge *ea*, 1991(2 times)				
RD19	Thailand	1987	•	n	0.18	Puckridge *et al.*, 1991				
RD19	Thailand	1987	•	n	0.26	Puckridge *ea*, 1991(2 times)				
RD19	Thailand	1987	•	n	0.27	Puckridge *et al.*, 1991				
RD19	Thailand	1987	•	n	0.28	Puckridge *et al.*, 1991				
SPR'76	Thailand	1988	•	n	0.25	Puckridge *et al.*, 1991				
SPR'76	Thailand	1988	•	n	0.31	Puckridge *et al.*, 1991				
SPR'76	Thailand	1988	•	n	0.56	Puckridge *et al.*, 1991				
WHEAT										
•	Nigeria	75-76	•	n	0.39	8.2b	•	•	•	•
•	Nigeria	76-77	•	n	0.64	8.2b	•	•	•	•
SA INTA	Argentina	1986	•	n	0.40	Echeverria *et al.*, 1992				
SA INTA	Argentina	1986	•	n	0.64	Echeverria *et al.*, 1992				
SA INTA	Argentina	1986	•	n	0.39	Echeverria *et al.*, 1992				
SA INTA	Argentina	1986	•	n	0.59	Echeverria *et al.*, 1992				
Condor	Australia	1984	218	n	0.30	Whitfield & Smith, 1992				
Condor	Australia	1984	irr	n	0.48	Whitfield & Smith, 1992				
Condor	Australia	1985	340	n	0.42	Whitfield & Smith, 1992				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
WHEAT										
Condor	Australia	1985	340	n	0.35	Whitfield & Smith, 1992				
Condor	Australia	1985	irr	n	0.72	Whitfield & Smith, 1992				
Condor	Australia	1985	irr	n	0.74	Whitfield & Smith, 1992				
Condor	Australia	1987	267	n	0.23	Whitfield & Smith, 1992				
Condor	Australia	1987	267	n	0.13	Whitfield & Smith, 1992				
Condor	Australia	1987	irr	n	0.47	Whitfield & Smith, 1992				
Condor	Australia	1987	irr	n	0.52	Whitfield & Smith, 1992				
Gamenya	Australia	•	•	n	0.48	van Keulen, 1977				
•	Australia	•	•	•	0.28	van Keulen & van Heemst,'82				
Capella	Britain	69-78	•	n	0.42	Thorne *et al.*, 1988				
Capella	Britain	76-78	•	n	0.27	Thorne *et al.*, 1988				
Capella	Britain	76-78	•	man	0.22	Thorne *et al.*, 1988				
Flanders	Britain	69-84	•	n	0.69	Thorne *et al.*, 1988				
Flanders	Britain	69-78	•	man	1.21	Thorne *et al.*, 1988				
Opal	Canada	•	•		0.39	Bishop & MacEachern, 1971				
Opal	Canada	•	•		0.45	Bishop & MacEachern, 1971				
Opal	Canada	•	•		0.38	Bishop & MacEachern, 1971				
Norstar	Canada	85-86	•	n	0.15	Johnston & Fowler, 1991				
Norstar	Canada	85-86	•	n	0.14	Johnston & Fowler, 1991				
Norstar	Canada	85-86	•	n	0.21	Johnston & Fowler, 1991				
Norstar	Canada	86-87	•	n	0.13	Johnston & Fowler, 1991				
Norstar	Canada	86-87	•	n	0.18	Johnston & Fowler, 1991				
Norstar	Canada	87-88	•	n	0.12	Johnston & Fowler, 1991				
Norstar	Canada	87-88	•	n	0.11	Johnston & Fowler, 1991				
Kyperounda	Cyprus	70-71	•	n	0.26	Orphanos & Krentos, 1980				
Kyperounda	Cyprus	71-72	•	n	0.06	Orphanos & Krentos, 1980				
Pitic	Cyprus	70-71	•	n	0.36	Orphanos & Krentos, 1980				
Pitic	Cyprus	71-72	•	n	0.05	Orphanos & Krentos, 1980				
•	Germany	•	•	•	0.73	van Keulen, 1982				
•	Germany	•	•	•	0.33	van Keulen, 1982				
Vergina	Greece	1987	•	n	0.40	Papakosta & Gagianas, 1991				
Vergina	Greece	1987	•	n	0.47	Papakosta & Gagianas, 1991				
Yecora	Greece	1987	•	n	0.50	Papakosta & Gagianas, 1991				
Yecora	Greece	1987	•	n	0.56	Papakosta & Gagianas, 1991				
Santa	Greece	1987	•	n	0.41	Papakosta & Gagianas, 1991				
Santa	Greece	1987	•	n	0.60	Papakosta & Gagianas, 1991				
Mexicali	Greece	1987	•	n	0.35	Papakosta & Gagianas, 1991				
Mexicali	Greece	1987	•	n	0.53	Papakosta & Gagianas, 1991				
•	India	1974	•	n	0.54	8.2a	1	•	•	
•	India	1975	•	n	0.49	8.2a	1	•	•	
•	India	1974	•	n	0.10	8.2a (residual effect)				
•	India	1975	•	n	0.10	8.2a (residual effect)				
Sonara-64	India	67-68	•	n	0.34	Khetawat *et al.*, 1972				
•	India	68-69	•	n	0.66	Lal & Sharma, 1974				
•	India	69-70	•	n	0.73	Lal & Sharma, 1974				
•	India	1972	•	•	0.53	Kapur & Sekhon, 1977 (+ P, K)				
LOK1	India	83-87	•	n	0.95	Maliwal, 1990 (after)				
LOK1	India	83-87	•	n	1.17	Maliwal, 1990 (groundnut)				
LOK1	India	83-87	•	n	1.11	Maliwal, 1990 (idem)				
•	India	74-75	•	n	0.10	Sharma & Prasad, 1980				
•	India	74-75	•	n	0.10	Sharma & Prasad, 1980				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
WHEAT										
WL1562	India	84-85	irr	n	0.37	Sharma *et al.*, 1992				
WL1562	India	84-85	irr	n	0.30	Sharma *et al.*, 1992				
WL1562	India	84-85	irr	n	0.27	Sharma *et al.*, 1992				
WL1562	India	85-86	irr	n	0.69	Sharma *et al.*, 1992				
WL1562	India	85-86	irr	n	0.59	Sharma *et al.*, 1992				
WL1562	India	85-86	irr	n	0.54	Sharma *et al.*, 1992				
•	India	63-64	•	n	0.69	Singh *et al.*, 1971				
•	India	64-65	•	n	0.22	Singh *et al.*, 1971				
HD2281	India	84-86	•	n	0.54	Verma & Singh, 1991				
Donata	Netherlands	77-78	•	•	0.74	Ellen & Spiertz, 1980				
Donata	Netherlands	77-78	•	•	0.65	Ellen & Spiertz, 1980				
Arminda	Netherlands	82-83	•	n	0.66	Groot, 1987				
Arminda	Netherlands	82-83	•	n	0.94	Groot, 1987				
Arminda	Netherlands	82-83	•	n	0.78	Groot, 1987				
Arminda	Netherlands	83-84	•	n	0.52	Groot, 1987				
Arminda	Netherlands	83-84	•	n	1.15	Groot, 1987				
Arminda	Netherlands	83-84	•	n	0.22	Groot, 1987				
•	Netherlands	•	•	n	0.40	van Keulen, 1977				
•	Netherlands	•	•	n	0.34	van Keulen, 1977				
Ibis	Netherlands	1965	•	n	0.41	van Keulen, 1977				
Ibis	Netherlands	1965	•	n	0.51	van Keulen, 1977				
Ibis	Netherlands	1966	•	n	0.66	van Keulen, 1977				
•	Netherlands	•	•	•	0.40	van Keulen, 1982				
•	Netherlands	•	•	•	0.73	van Keulen, 1982				
•	Netherlands	•	•	•	0.40	van Keulen, 1982				
•	Netherlands	•	•	•	0.17	van Keulen, 1982				
•	Netherlands	•	•	•	0.43	van Keulen & van Heemst,'82				
•	Netherlands	•	•	•	0.75	van Keulen & van Heemst,'82				
Lely	Netherlands	1975	•	n	0.69	Spiertz & Ellen, 1978				
Mexipak65	Pakistan	69-70	•	n	0.48	Hamid, 1973				
Mexipak65	Pakistan	69-70	•	n	0.60	Hamid, 1973				
Mexicani	Sudan	73-74	•	n	0.33	Khalifa *et al.*, 1977				
Mexicani	Sudan	73-74	•	n	0.21	Khalifa *et al.*, 1977				
Fortana	USA	1968	•	•	0.00	Black, 1970				
Fortana	USA	1968	•	•	0.35	Black, 1970				
Fortana	USA	1968	•	•	0.45	Black, 1970				
Fortana	USA	1968	•	•	0.51	Black, 1970				
Fortana	USA	1968	•	•	0.73	Black, 1970				
Yolo	USA	87-88	irr	n	0.59	Cassman *et al.*, 1992				
Yolo	USA	87-88	irr	n	0.47	Cassman *et al.*, 1992				
Yolo	USA	87-88	irr	n	0.50	Cassman *et al.*, 1992				
Yolo	USA	87-88	irr	n	0.54	Cassman *et al.*, 1992				
Arthur	USA	1967	•	•	0.48	Eilrich & Hageman, 1973				
Arthur	USA	1967	•	•	0.55	Eilrich & Hageman, 1973				
Arthur	USA	1967	•	•	0.49	Eilrich & Hageman, 1973				
Arthur	USA	1967	•	•	0.07	Eilrich & Hageman, 1973				
Arthur	USA	1967	•	•	0.31	Eilrich & Hageman, 1973				
Newana	USA	1977	•	•	0.25	Jones *et al.*, 1981				
Newana	USA	1977	•	•	0.38	Jones *et al.*, 1981				
Newana	USA	1977	•	•	0.51	Jones *et al.*, 1981				
Selkirk	USA	•	•		0.15	Racz *et al.*, 1965				

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Table A1.1. Continued.

CROP	Country	Year	P	OM	NFR	Fig	N_{am}	FT	AT	ST
WHEAT										
Selkirk	USA	•	•		0.10	Racz *et al.*, 1965				
Selkirk	USA	•	•		0.08	Racz *et al.*, 1965				
Selkirk	USA	•	•		0.20	Racz *et al.*, 1965				
Yecora	USA	88/89	irr	n	0.39	Wuest & Cassman, 1992				
Yecora	USA	88/89	irr	n	0.23	Wuest & Cassman, 1992				
Yecora	USA	88/89	irr	n	0.03	Wuest & Cassman, 1992				
GROUNDNUT										
55-437	Niger	1089	•	n	0.55	Hafner *et al.*, 1992				
•	Senegal	1964	•	n	2.49	10.1a	14	•	•	•
•	Senegal	1964	•	n	3.44	10.1a	10	•	•	•
•	Senegal	•	•	n	1.33	10.1b	9	•	•	1
•	Senegal	•	•	n	2.64	10.1b	10	•	•	3
•	Senegal	•	•	n	0.63	10.1c	15	•	•	1
•	Senegal	•	•	n	0.69	10.1c	10	•	•	3
•	Senegal	•	•	n	3.33	10.1d	9	•	•	1
•	Senegal	•	•	n	4.25	10.1d	8	•	•	3
•	Senegal	•	•	n	0.57	10.1e	20	1	1	1
•	Senegal	•	•	n	0.53	10.1e	25	1	1	1
•	Senegal	•	•	n	0.50	10.1e	25	1	1	1
•	Senegal	•	•	n	-0.17	10.1f	30	1	1	1
•	Senegal	•	•	n	0.17	10.1f	30	1	2	1
•	Senegal	•	•	n	-0.80	10.1f	15	•	•	1
•	Senegal	•	•	n	-0.27	10.1f	15	•	•	1

Additional available, but not incorporated due to time restrictions:
sorghum: 36 values ranging from 0.23-0.82 (Powell & Hons, 1992);
maize: 0.20, 0.22, 0.23, 0.25, 0.41 (Eichelberger *et al.*, 1989);
rice: 0.54, 0.46, 0.35 (Kropff *et al.*, 1992);
wheat: 0.15, 0.21 (Gauer *et al.*, 1992).

Table A1.2. *Phosphorus fertilizer recoveries (PFR, kg kg^{-1}) in total above-ground biomass of the various crops as derived from the constructed figures in Part B or from cited literature.*
P: annual precipitation (mm), irr = irrigated; OM: yes or no application of organic matter (manure, straw);
P_{am}: maximum application level for validity of regression line (kg ha^{-1}) in the figure referred to;
FT: fertilizer type: 1 = triple superphosphate, 2 = NPK, 3 = NP, 4 = natural phosphate, 5 = single superphosphate, 6 = ammonium phosphate, 7 = bicalcium phosphate;
AT: application time: 1 = at ploughing/after emergence, 2 = as 1 + at anthesis;
ST: Soil type: 1 = sand, 2 = sandy loam, 3 = sandy clay, 4 = clay, 5 = silty clay loam. • = unknown.

CROP	Country	Year	P	OM	PFR	Fig	P_{am}	FT	AT	ST
MILLET										
Souna	Mali	1982	•	n	0.13	4.4a	45	1	3	•
Souna	Mali	1982	•	n	0.37	4.4a	20	2	•	•
Niou Bobo	Mali	1971	•	n	0.20	4.4e	45	1	•	•
Niou Bobo	Mali	1971	•	n	0.09	4.4e	10	4	•	•
Niou Bobo	Mali	1971	•	n	0.19	4.4f	70	1	•	•
Niou Bobo	Mali	1971	•	n	0.12	4.4f	70	4	•	•
P3 Kolo	Niger	1969	•	n	0.24	4.4c	35	4	•	•
P3 Kolo	Niger	1970	•	n	0.16	4.4c	30	4	•	•
P3 Kolo	Niger	1971	•	n	0.07	4.4c	30	4	•	•
	Niger	1987	•	n	0.23	4.4g	13	5	•	•
Souna III	Senegal	1988	917	n	0.13	4.4d	14	2	2	1
Souna III	Senegal	1988	917	m	0.27	4.4d	14	2	2	1
•	India	1972	•	n	0.13	4.4b	13	1	•	•
Bajra	India	1971	•	•	0.04	Lal, 1979				
Bajra	India	1972	•	•	0.03	Lal, 1979				
BK560	India	75-76	irr	n	0.06	Munda *et al.*, 1984				
HB1	India	•	•	•	0.44	Singh & Randhawa, 1979 (+N)				
SORGHUM										
S29	Burkina	•	•	n	0.17	5.4b	22	3	•	•
S29	Burkina	•	•	m	1.09	5.4b	22	3	•	•
S29	Burkina	•	•	n	0.16	5.4d	40	•	•	•
Soninkoura	Mali	•	•	n	0.07	5.4a	70	3	•	•
Pioneer846	Australia	70-71	•	•	0.07	Myers, 1978b				
Pioneer846	Australia	71-72	•	•	0.04	Myers, 1978b				
CSH-I	India		•	n	0.18	5.4c	25	•	•	•
CSH-I	India		•	n	0.22	5.4c	25	3	•	•
CSH-I	India		•	n	0.38	5.4c	25	3	•	•
fodder s.	India	1965	•	n	0.14	Singh & Pancholy, 1967				
•	India	69-71	•	•	0.10	Turkhede & Prasad, 1980				
Wade Aker	Sudan	1961	•	n	0.09	5.4e	37	1	1	4
Wade Aker	Sudan	1961	•	n	0.11	5.4e	37	1	1	4
Wade Aker	Sudan	1961	•	n	0.20	5.4e	37	1	1	4
Wade Aker	Sudan	1961	•	n	0.17	5.4e	37	1	1	4

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Table A1.2. Continued.

CROP	Country	Year	P	OM	PFR	Fig	P_{am}	FT	AT	ST
MAIZE										
Tiementie	Mali	1971	•	n	0.33	6.3a	35	1	•	•
Tiementie	Mali	1971	•	n	0.18	6.3a	70	4	•	•
Tiementie	Mali	1971	•	n	0.31	6.3b	37	1	•	•
TZAxTZB	Nigeria	•	•	n	0.33	6.3c	60	5+NK	•	•
TZAxTZB	Nigeria	•	•	n	0.23	6.3c	60	5+NK	•	•
TZAxTZB	Nigeria	1971	•	n	0.27	Kang & Osiname, 1979				
S.123	Nigeria	76-77	•	n	0.20	Singh & Balasubrama., 1983				
•	Nigeria	1973	1396	n	0.13	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.18	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.21	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.23	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.23	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.15	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.15	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.10	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.13	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.14	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.15	Atanasiu *et al.*, 1978				
•	Nigeria	1973	1396	n	0.16	Atanasiu *et al.*, 1978				
NS1	Nigeria	•	•	n	0.00	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.02	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.02	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.03	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.04	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.11	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.06	Adepetu & Corey, 1977				
NS1	Nigeria	•	•	n	0.14	Adepetu & Corey, 1977				
	Brazil	•	•	•	0.02	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.03	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.02	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.04	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.01	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.02	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.01	Janssen *et al.*, 1987				
•	Brazil	•	•	•	0.02	Janssen *et al.*, 1987				
•	India	1972	•	•	0.70	Kapur & Sekhon, 1977 (+ N, K)				
Ganga 5	India	1985	•	n	0.34	Totawat & Saeed, 1990				
Ganga 5	India	84-86	•	n	0.16	Verma & Singh, 1991				
Mexican	Sudan	1961	•	n	0.06	6.3d	38	•	1	1
June	Sudan	1961	•	n	0.14	6.3d	38	•	1	1
Mexican	Sudan	1961	•	n	0.06	6.3d	38	•	1	1
June	Sudan	1961	•	n	0.14	6.3d	38	•	1	1
Mexican	Sudan	1961	•	n	0.00	6.3e	38	•	1	1
June	Sudan	1961	•	n	0.00	6.3e	38	•	1	1
Mexican	Sudan	1961	•	n	0.00	6.3e	38	•	1	1
June	Sudan	1961	•	n	0.01	6.3e	38	•	1	1

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Table A1.2. Continued.

CROP	Country	Year	P	OM	PFR	Fig	P_{am}	FT	AT	ST
RICE										
IDSA6	Ivory C.	1989	•	n	0.07	7.3k	25	1+N	•	4
IDSA6	Ivory C.	1989	•	n	0.08	7.3k	25	1+K	•	4
IDSA6	Ivory C.	1989	•	n	0.08	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.13	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.08	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.08	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.02	Koopmans, 1990 (+K fert.)				
IDSA6	Ivory C.	1989	•	n	0.07	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.11	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.08	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.07	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.09	Koopmans, 1990 (+N fert.)				
BG79	Nigeria	58-61	•	n	0.14	7.3a	17	5	•	4
BG79	Nigeria	58-61	•	n	0.14	7.3a	17	5+N	•	4
BG79	Nigeria	58-61	•	n	0.07	7.3a	36	5+N	•	4
BG79	Nigeria	58-61	•	n	0.04	7.3b	36	5	•	1
BG79	Nigeria	58-61	•	n	0.01	7.3b	36	5+N	•	1
BG79	Nigeria	58-61	•	n	0.06	7.3b	36	5+N	•	1
IR8	Senegal	1968	•	n	0.004	7.3j	220	3	•	•
IR8	Senegal	1968	•	n	0.08	7.3j	220	3	•	•
IR8	Senegal	1968	•	n	-0.01	7.3j	220	1	•	•
TN1	Senegal	1970	•	n	0.21	7.3c	45	1	•	4
TN1	Senegal	70-71	•	n	0.22	7.3c	45	1	•	4
TN1	Senegal	1971	•	n	0.17	7.3c	45	1	•	4
TN1	Senegal	1970	•	n	0.28	7.3d	45	6	•	4
TN1	Senegal	70-71	•	n	0.24	7.3d	45	6	•	4
TN1	Senegal	1971	•	n	0.24	7.3d	45	6	•	4
TN1	Senegal	1970	•	n	0.29	7.3e	45	7	•	4
TN1	Senegal	70-71	•	n	0.18	7.3e	45	7	•	4
TN1	Senegal	1971	•	n	0.22	7.3e	45	7	•	4
TN1	Senegal	1970	•	n	0.05	7.3f	45	4	•	4
TN1	Senegal	70-71	•	n	0.16	7.3f	45	4	•	4
TN1	Senegal	1971	•	n	0.11	7.3f	45	4	•	4
TN1	Senegal	1970	•	n	0.17	7.3g	45	4	•	4
TN1	Senegal	1971	•	n	0.19	7.3g	45	4	•	4
TN1	Senegal	1970	•	n	0.06	7.3h	45	4	•	4
TN1	Senegal	70-71	•	n	0.14	7.3h	45	4	•	4
TN1	Senegal	1971	•	n	0.15	7.3h	45	4	•	4
TN1	Senegal	1970	•	n	0.10	7.3i	45	4	•	4
TN1	Senegal	70-71	•	n	0.15	7.3i	45	4	•	4
TN1	Senegal	1971	•	n	0.17	7.3i	45	4	•	4
IAC47	Brazil	77-78	•	•	0.06	Fageria *et al.*, 1982				
IAC47	Brazil	78-79	•	•	0.10	Fageria *et al.*, 1982				
C10754	India	1976	•	•	0.35	Bhushan & Singh, 1979				
Sarjoo 49	India	•	•	•	0.19	Agarwal, 1980				
•	India	1966	•	n	0.18	Mahapatra & Pande, 1972				
•	India	1967	•	n	0.11	Mahapatra & Pande, 1972				
Raghusail	India	1964	•	•	0.02	Majumdar, 1973				
Raghusail	India	1964	•	•	0.01	Majumdar, 1973				
•	India	•	•	•	0.01	Mehrotra *et al.*, 1968 (- N)				

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Table A1.2. Continued.

CROP	Country	Year	P	OM	PFR	Fig	P_{am}	FT	AT	ST
RICE										
•	India	•	•	•	0.11	Mehrotra *et al.*, 1968 (+ N)				
•	India	•	•	•	0.09	Mehrotra *et al.*, 1968 (+ N)				
•	India	•	•	•	0.12	Mehrotra *et al.*, 1968 (+ N)				
•	India	•	•	•	0.13	van Keulen & van Heemst,'82				
•	Indonesia	•	•	•	0.05	Palmer *et al.*, 1990				
•	Madagascar	•	•	•	0.03	Jansssen *et al.*, 1987				
•	Madagascar	•	•	•	0.02	Jansssen *et al.*, 1987				
•	Madagascar	•	•	•	0.02	Jansssen *et al.*, 1987				
•	Madagascar	•	•	•	0.02	Jansssen *et al.*, 1987				
•	Madagascar	•	•	•	0.02	Jansssen *et al.*, 1987				
•	Phillippines	•	•	n	0.45	Garrity *et al.*, 1990 (+ N)				
Muey N.62	Thailand	1968	•	•	0.11	Koyama & Chammek, 1971				
Dawk Mali	Thailand	1968	•	•	0.15	Koyama & Chammek, 1971				
	Thailand	1988	•	•	0.03	Palmer *et al.*, 1990				
WHEAT										
S. Cerros	Nigeria	76-77	•	n	0.19	Singh & Balasubraman., 1983				
•	India	•	•	•	0.22	Prasad *et al.*, 1985				
•	India	63-64	•	n	0.04	Singh *et al.*, 1971				
•	India	64-65	•	n	0.00	Singh *et al.*, 1971				
•	India	1972	•	•	0.33	Kapur & Sekhon, 1977 (+ N, K)				
HD2285	India	85-86	•	n	0.18	Venugopalan & Prasad, 1989				
HD2285	India	86-87	•	n	0.10	Venugopalan & Prasad, 1989				
HD2281	India	84-86	•	n	0.19	Verma & Singh, 1991				
•	India	•	•	•	0.17	van Keulen & van Heemst,'82				
•	India	•	•	•	0.19	van Keulen & van Heemst,'82				
•	India	•	•	•	0.21	van Keulen & van Heemst,'82				
Sham 1	Syria	1985	•	n	0.03	Matar & Brown, 1989				
Sham 1	Syria	1985	•	n	0.07	Matar & Brown, 1989				
Sham 1	Syria	1985	•	n	0.07	Matar & Brown, 1989				
Sham 1	Syria	1986	•	n	0.02	Matar & Brown, 1989				
Sham 1	Syria	1986	•	n	0.02	Matar & Brown, 1989				
Sham 1	Syria	1986	•	n	0.08	Matar & Brown, 1989				
Sham 1	Syria	1987	•	n	0.01	Matar & Brown, 1989				
Sham 1	Syria	1987	•	n	0.03	Matar & Brown, 1989				
Sham 1	Syria	1987	•	n	0.10	Matar & Brown, 1989				
•	Turkey	•	•	n	0.15	8.3a	55	•	•	•
•	Turkey	•	•	n	0.06	8.3a	55	•	•	•
Fortuna	USA	1968	•	n	0.04	Black, 1970				
Fortuna	USA	1968	•	n	0.07	Black, 1970				
Fortuna	USA	1968	•	n	0.06	Black, 1970				
Selkirk	USA	•	•	n	0.06	Racz *et al.*, 1965				
Selkirk	USA	•	•	n	0.00	Racz *et al.*, 1965				
Selkirk	USA	•	•	n	0.06	Racz *et al.*, 1965				
Selkirk	USA	•	•	n	0.04	Racz *et al.*, 1965				
Centurk78	USA	1983	•	n	0.17	Sanders *et al.*, 1991 (knifed)				
Centurk78	USA	1983	•	n	0.09	Sanders *ea*, 1991 (broadcast)				
Centurk78	USA	1983	•	n	0.16	Sanders *ea*,'91 (seed applied)				

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Table A1.2. Continued.

CROP	Country	Year	P	OM	PFR	Fig	P_{am}	FT	AT	ST
GROUNDNUT										
•	Senegal	1964	•	n	0.30	10.2a	5	3	•	•
•	Senegal	•	•	n	0.08	10.2b	13	•	•	1
•	Senegal	•	•	n	0.05	10.2b	13	•	•	•
•	Senegal	•	•	n	0.17	10.2b	13	•	•	•
COWPEA										
•	India	•	•	n	0.13	11.2a	13	1	1	•
COTTON										
•	Turkey	•	•	n	0.10	13.2a	55	•	•	•
•	Turkey	•	•	n	0.13	13.2a	55	•	•	•

Table A1.3. *Potassium fertilizer recoveries (KFR, kg kg^{-1}) in total above-ground biomass of the various crops as derived from the constructed figures in Part B or the quoted literature.*
P: annual precipitation (mm); OM: yes or no application of organic matter (manure, straw); K_{am}: maximum application level for validity of regression line (kg ha^{-1}) in the figure referred to; FT: fertilizer type: 1 = NPK, 2 = NK, 3 = KCl + NP; 4 = Muriate of potash; AT: application time: 1 = at ploughing/after emergence, 2 = as 1 + at anthesis;
ST: Soil type: 1 = sand, 2 = sandy loam, 3 = sandy clay, 4 = clay; 5 = oxisol; • = unknown.

CROP	Country	Year	P	OM	KFR	Fig	K_{am}	FT	AT	ST
MILLET										
Souna III	Senegal	•	•	n	1.69	4.5a	90	1	•	•
Souna III	Senegal	1973	406	n	0.22	4.5b	70	1	•	•
Souna III	Senegal	1974	502	n	0.37	4.5b	50	1	•	•
Souna III	Senegal	1976	403	n	1.39	4.5c	80	1	•	•
Souna III	Senegal	1976	•	str	1.04	4.5c	80	1	•	•
Souna III	Senegal	1977	391	n	2.04	4.5d	80	1	•	•
Souna III	Senegal	1977	391	str	1.58	4.5d	80	1	•	•
Souna III	Senegal	1988	917	n	0.73	4.5f	25	1	1	•
Souna III	Senegal	1988	917	man	2.20	4.5f	25	1	1	•
•	India	•	•	n	3.6	4.5e	•	•	•	•
Bajra	India	•	•	•	0.34	Lal, 1979				
Bajra	India	•	•	•	0.26	Lal, 1979				
MAIZE										
TZAxTZB	Nigeria	•	•	n	4.39	6.4a	30	1	•	•
TZAxTZB	Nigeria	•	•	n	2.91	6.4a	30	1	•	•
S.123	Nigeria	76-77	•	n	0.24	Singh & Balasubraman., 1983				
•	France	1956	•	n	0.41	Loué, 1963				
•	France	1956	•	man	0.50	Loué, 1963				
•	India	1972	•	•	1.34	Kapur & Sekhon, 1977 (+N, P)				
DeKalb	USA	1977	•	n	0.17	6.4b	250	3	•	•
DeKalb	USA	1977	•	n	0.11	6.4b	90	3	•	•
DeKalb	USA	1977	•	n	0.60	Sparks *et al.*, 1980				
RICE										
IDSA6	Ivory C.	1989	•	n	0.22	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.53	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.38	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.49	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.14	Koopmans, 1990 (+P fert.)				
IDSA6	Ivory C.	1989	•	n	0.00	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.10	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.06	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.00	Koopmans, 1990 (+N fert.)				
IDSA6	Ivory C.	1989	•	n	0.24	Koopmans, 1990 (+N fert.)				
TN1	Senegal	69-70	•	n	0.72	7.4a	80	3	•	1
TN1	Senegal	69-70	•	str	0.29	7.4a	80	3	•	1
TN1	Senegal	1970	•	n	0.27	7.4a	80	3	•	1

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Table A1.3. Continued.

CROP	Country	Year	P	OM	KFR	Fig	K_{am}	FT	AT	ST
RICE										
TN1	Senegal	1970	•	str	0.58	7.4a	80	3	•	1
TN1	Senegal	70-71	•	n	0.27	7.4b	80	3	•	1
TN1	Senegal	70-71	•	str	0.25	7.4b	80	3	•	1
TN1	Senegal	1971	•	n	0.13	7.4b	80	3	•	1
TN1	Senegal	1971	•	str	0.01	7.4b	80	3	•	1
TN1	Senegal	1972	•	n	0.19	7.4c	80	3	•	1
TN1	Senegal	1972	•	str	0.20	7.4c	80	3	•	1
Sarjoo 49	India	•	•	•	0.14	Agarwal, 1980				
•	India	1966	•	n	1.03	Mahapatra & Pande,1972(+NP)				
•	India	1967	•	n	0.52	Mahapatra & Pande,1972(+NP)				
Ngoba	India	81-83	•	n	0.11	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.28	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.26	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.24	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.31	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.40	Ram & Prasad, 1985				
Ngoba	India	81-83	•	n	0.21	Ram & Prasad, 1985				
Sentani	Indonesia	84-85	•	•	0.68	7.4e	150	3	•	5
Sentani	Indonesia	85-86	•	•	2.46	7.4e	100	3	•	5
•	Madagascar	1968	•	n	0.31	7.4d		1	•	•
•	Madagascar	68-69	•	n	0.58	7.4d		1	•	•
•	Madagascar	1969	•	n	0.63	7.4d		1	•	•
IR36	Phillippines	'84	•	n	0.58	de Datta, 1985				
IR36	Phillippines	'84	•	n	0.66	de Datta, 1985				
IR36	Phillippines	'84	•	n	0.60	de Datta, 1985				
IR5931	Phillippines	'84	•	n	0.51	de Datta, 1985				
IR5931	Phillippines	'84	•	n	0.44	de Datta, 1985				
IR5931	Phillippines	'84	•	n	0.54	de Datta, 1985				
WHEAT										
S. Cerros	Nigeria	76-77	•	n	0.21	Singh & Balasubraman., 1983				
HD2281	India	•	•	n	0.67	Verma & Singh, 1991				
•	India	1972	•	•	1.40	Kapur & Sekhon, 1977 (+N, P)				
•	Great Britain	•	•	n	0.11	8.4a	60	•	•	•
•	Great Britain	•	•	n	0.08	8.4a	60	•	•	•
•	Great Britain	•	•	n	0.12	8.4b	60	•	•	•
•	Great Britain	•	•	n	0.23	8.4b	60	•	•	•
GROUNDNUT										
•	Senegal	1964	•	n	0.31	10.3f	22	2	•	1
•	Senegal	1973	406	n	0.33	10.3a	70	1	•	1
•	Senegal	1974	502	n	0.10	10.3b	75	1	•	1
•	Senegal	1975	•	n	0.55	10.3c	21	1	•	1
•	Senegal	1976	403	n	0.33	10.3d	75	1	•	1
•	Senegal	1977	391	n	0.24	10.3e	75	1	•	1
•	Senegal	1974	502	str	0.52	10.3b	20	1	•	1
•	Senegal	1975	•	str	0.70	10.3c	21	1	•	1
•	Senegal	1976	403	str	0.34	10.3d	75	1	•	1
•	Senegal	1977	•	str	0.28	10.3e	75	1	•	1

ANNEX 2. NUTRIENT CONCENTRATION IN FARMYARD MANURE

ANNEX 2. NUTRIENT CONCENTRATION IN FARMYARD MANURE

Table A2.1. *Content of nutrient elements in manure under West African conditions (% of dry matter). Values between [ ] not used in this study.*

Average	Range	Country	Site	Reference
Nitrogen				
Cattle				
2.30		Burkina		Pichot *et al.*, 1981
2.47		Burkina		Pichot *et al.*, 1981
1.47		Burkina		Pichot *et al.*, 1981
1.28		Burkina		Quilfen & Milleville, 1983
1.18	0.92-1.44	Mali	South region	Richard quoted by Piéri, 1983
0.97	0.9 -1.3	Mali	South region	CMDT quoted by van de Pol, '92
0.83	0.6 -1.2	Mali	South region	van de Pol, 1988
1.10	0.9 -1.3	Mali	South region	van de Pol, 1992
0.35		Mali	5th Region	ADRAO, 1986
1.21		Niger	Sadore	Bationo & Mokwunye, 1991
1.25		Senegal	Thilmakha'83	Cissé, 1988
1.35		Senegal	Thilmakha'84	Cissé, 1988
1.46		Senegal	Thilmakha'85	Cissé, 1988
1.4		Senegal		Oliver quoted by Piéri, 1989
2.04-2.50		Senegal		CNRA quoted by Piéri, 1989
1.88		Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
2.0		general		Euroconsult, 1989
[1.62		India		Deshpande *et al.*, 1983]
[1.80		India		Sharma & Mittra, 1991]
small ruminants				
0.80		Mali	5th Region	ADRAO, 1986
2.20		Burkina		Quilfen & Milleville, 1983
2.0			general	Euroconsult, 1989
1.27		**USED IN THIS STUDY**		
Phosphorus				
Cattle				
0.21		Burkina		Pichot *et al.*, 1981
0.20		Burkina		Pichot *et al.*, 1981
0.22		Burkina		Pichot *et al.*, 1981
0.24		Burkina		Pichot *et al.*, 1981
0.11		Burkina		Quilfen & Milleville, 1983
0.32	0.26-0.38	Mali	South region	Richard quoted by Piéri, 1983
0.17	0.16-0.18	Mali	South region	CMDT quoted by van de Pol, '92
0.17	0.13-0.24	Mali	South region	van de Pol, 1988
0.20	0.15-0.35	Mali	South region	van de Pol, 1992
0.23		Mali	5th Region	ADRAO, 1986
0.41		Niger	Sadore	Bationo & Mokwunye, 1991
0.35		Senegal	Thilmakha '83	Cissé, 1988
0.28		Senegal	Thilmakha '84	Cissé, 1988
0.34		Senegal	Thilmakha '85	Cissé, 1988
0.30	0.13-0.68	Senegal		Oliver quoted by Piéri, 1989

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Table A2.1. Continued.

Average Range	Country	Site	Reference
Phosphorus			
Cattle			
0.23-0.56	Senegal		CNRA quoted by Piéri, 1989
0.32	Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
0.66	general		Euroconsult, 1989
[0.22	India		Deshpande *et al.*, 1983]
[0.23	India		Sharma & Mittra, 1991]
small ruminants			
0.12	Burkina		Quilfen & Milleville, 1983
0.35	Mali	5th Region	ADRAO, 1986
0.66	general		Euroconsult, 1989
0.28	**USED IN THIS STUDY**		
Potassium			
Cattle			
4.50	Burkina		Pichot *et al.*, 1981
4.30	Burkina		Pichot *et al.*, 1981
1.60	Burkina		Pichot *et al.*, 1981
0.46	Burkina		Quilfen & Milleville, 1983
1.501.1 -1.9	Mali	South region	Richard quoted by Piéri, 1983
1.281.18-1.39	Mali	South region	CMDT quoted by van de Pol, '92
1.291.00-1.99	Mali	South region	van de Pol, 1988
1.301.15-1.60	Mali	South region	van de Pol, 1992
1.03	Senegal	Thilmakha '83	Cissé, 1988
1.52	Senegal	Thilmakha '84	Cissé, 1988
1.81	Senegal	Thilmakha '85	Cissé, 1988
1.220.20-2.92	Senegal		Oliver quoted by Piéri, 1989
1.46-3.98	Senegal		CNRA quoted by Piéri, 1989
1.78	Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
1.66	general		Euroconsult, 1989
[2.04	India		Sharma & Mittra, 1991]
small ruminants			
0.73	Burkina		Quilfen & Milleville, 1983
2.5	general		Euroconsult, 1989
1.30	**USED IN THIS STUDY**		
Carbon			
Cattle			
27.3	Burkina		Pichot *et al.*, 1981
35.0	Burkina		Pichot *et al.*, 1981
21.7	Burkina		Pichot *et al.*, 1981
32.1	Niger	Sadore	Bationo & Mokwunye, 1991
23.5	Senegal	Thilmakha '84	Cissé, 1988
28.3	Senegal	Thilmakha '85	Cissé, 1988
33.5	Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
[25.5	India		Sharma & Mittra, 1991]

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Table A2.1. Continued.

Average Range	Country	Site	Reference
Calcium			
Cattle			
1.30	Burkina		Pichot *et al.*, 1981
1.70	Burkina		Pichot *et al.*, 1981
1.00	Burkina		Pichot *et al.*, 1981
1.10	Burkina		Pichot *et al.*, 1981
0.89	Mali	South region	Richard quoted by Piéri, 1983
0.43-0.71	Mali	South region	van de Pol, 1988
1.21	Senegal	Thilmakha '83	Cissé, 1988
1.65	Senegal	Thilmakha '84	Cissé, 1988
1.56	Senegal	Thilmakha '85	Cissé, 1988
1.140.36-2.06	Senegal		Oliver quoted by Piéri, 1989
1.86-3.50	Senegal		CNRA quoted by Piéri, 1989
1.60	Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
2.86	general		Euroconsult, 1989
small ruminants			
1.43-3.57	general		Euroconsult, 1989
Magnesium			
Cattle			
0.77	Burkina		Pichot *et al.*, 1981
0.68	Burkina		Pichot *et al.*, 1981
0.67	Burkina		Pichot *et al.*, 1981
0.49	Burkina		Pichot *et al.*, 1981
0.42	Mali	South region	Richard quoted by Piéri, 1983
0.12-0.42	Mali	South region	van de Pol, 1988
0.48	Senegal	Thilmakha '83	Cissé, 1988
0.16	Senegal	Thilmakha '84	Cissé, 1988
0.68	Senegal	Thilmakha '85	Cissé, 1988
0.490.12-0.80	Senegal		Oliver quoted by Piéri, 1989
0.81-1.28	Senegal		CNRA quoted by Piéri, 1989
0.67	Senegal	Nioro 1988	van Duivenbooden & Cissé, 1989
0.60	general		Euroconsult, 1989
small ruminants			
1.21	general		Euroconsult, 1989
Sulfur			
cattle			
0.15	Mali	South region	Richard quoted by Piéri, 1983
0.20	general		Euroconsult, 1989
small ruminants			
0.60	general		Euroconsult, 1989
Sodium			
cattle			
0.25	Burkina		Pichot *et al.*, 1981
0.18	Burkina		Pichot *et al.*, 1981

ANNEX 3. LIST OF ACRONYMS AND ABBREVIATIONS

ADRAO	= Association pour le Développement de la Riziculture en Afrique de l'Ouest (synonym WARDA = West Africa Rice Development Association)
CABO	= Centre for Agrobiological Research
d	= day
DM	= dry matter
ESPR	= Equipe chargée de l'Etude sur les Systèmes de Productions Rurales en 5ème Région et Cercle de Niafunké
FAO	= Food and Agricultural Organisation of the United Nations
FHI	= Fruit harvest index ((grains+pods)/total above-ground bioamass)
GFR	= Grain fruit ratio = Grain/(Grain+pods)
ha	= hectare
HI	= harvest index (=grain/total above-ground biomass)
ox	= oxen
PIRT	= Projet Inventaire des Ressources Terrestres - Mali
PPIV	= small village irrigation scheme
RFMC	= République Francaise, Ministère de la Coopération
RIM	= Resource Inventory and Management Ltd.
t	= metric ton or tonne (1000 kg)
TAC	= Technical Advisory Committee to the Consultative Group on International Agricultural Research
yr	= year