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and Cover Crops in the
Rwandan Highlands

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HERBACEOUS LEGUMES AS NUTRIENT SOURCES AND COVER CROPS IN THE RWANDAN HIGHLANDS.

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ABSTRACT

Herbaceous legumes were assessed for their suitability as nutrient sources and as ground cover for the northern highlands of Rwanda. There were three investigations that followed the Farming Systems Research (FSR) methodology. First, exploratory studies were conducted to measure biomass yield and percentage ground cover. Second, 12 legumes were screened on station for biomass production, nutrient yield and ground cover. Yields of maize (Zea mays) grown as a test crop following incorporation of the legumes were compared with yields of maize grown at different nitrogen levels. Third, following farmers' comments on the second study's results, five legume species were chosen for multilocational testing on 11 farmers' fields. Preliminary studies showed high biomass yields and good ground covers for Desmodium spp., Trifolium spp., Vetch spp. and Stylosanthes spp. Trifolium repens (white clover) demonstrated a prostrate and complete ground cover--ideal characteristics for live-mulch species. On-station experiments indicated significant accumulation of nutrients by the legumes but with substantial site-species interaction. Legumes with high biomass yields decreased maize yields when compared with maize grown with no nitrogen. The multilocational testing confirmed the inconsistent performance of the species at different sites and led to the definition of three sub-regions (North, Central and South) for which different promising legumes were selected. Selection criteria such as vegetative yield, nutrient content and ground coverage resulted in the following selections by region and in order of preference: North--Canavalia, Lupin, Mucuna; Central--Vetch, Lupin; and South--Mucuna, Lupin and (on fertile soil) Canavalia. In terms of legume growth performance, this study suggests possible benefits from 1) moderate initial fertilization, 2) extended vegetative growth, 3) high sowing densities and 4) sowing in mixtures on infertile soils. Short-term crop yield losses due to net immobilization of soil nutrients by some cover crops (e.g. Vetch) may make these legumes unacceptable to small-scale farmers. Research on decomposition and nutrient release is recommended prior to extension of legumes to farmers.

INTRODUCTION

The role of herbaceous legumes in agricultural systems dates back to the early days of the Romans (Mundy, 1928). Lupin was one of the favored cover crops reported to have been used for soil fertility restoration in German farming systems.

In southern African agricultural systems, legumes, intercropped, relay cropped or grown in rotations with food crops, have proven beneficial to soil fertility management (Rattray and Ellis, 1952). At the International Institute of Tropical Agriculture (IITA) in Nigeria, farming systems that center around the use of herbaceous and shrub legumes have been developed (IITA, 1976-84). These systems, recognized by names such as living mulches, in-situ mulches, dead mulches and alley cropping, are generally superimposed on zero-tillage practices to provide organic matter, nutrients, particularly nitrogen (N), improvement in soil physical properties and soil erosion and runoff control (Wilson et al., 1982; Wilson and Kang, 1982; Lal et al., 1978; Akobundu, 1980; Kang et al., 1981). Other studies in tropical and temperate environments that lend support to the desirable effect of cover crops and no-till farming are Agboola, 1981; Kannegieter, 1969; Reddy et al., 1986; Singh and Awasthi, 1978 and Elkins et al., 1979. The potential of cover crops for soil productivity maintenance in Rwandan farming systems is yet to be fully exploited. Information pertaining to performance of potential species is limited, especially in the high-altitude regions of Rwanda.

This paper outlines the screening procedure used by the Farming System Research Program (FSRP) to select appropriate candidate species for each major agroecological zone in the study region and suggests ways of enhancing the contribution of legumes for soil fertility management in the land-limited FSRP area.

MATERIALS AND METHODS

The FSRP area is located in the northern highlands of Rwanda at longitude 29°53' east and latitude 1°32' south and borders southern Uganda to the north. Rainfall is bimodal in distribution with the minor rainy season lasting from March to June and the main season from September through March. The main dry season lasts from June to September. Total annual rainfall varies from 1200 to 1500 mm. The mean monthly temperature ranges from 13 to > 22 C though minimum temperatures have sometimes reached 5 C in the Buberuka Highlands. Soils in the eastern part of the project area are derived from granite while those in the west are derived from schists and quartzite and are classified in the USDA system as Oxisols. Elevation varies from 1500 to 2600 m.

Exploratory Study

Trials with herbaceous legumes were initiated at the Institute of Agronomic Sciences of Rwanda's (ISAR) high-altitude (2300-m) station in 1985. The objective of this exploratory study was to evaluate Desmodium spp., Vetch spp., Cajanus cajan and Trifolium sp. inter alia as fodder sources. Large-seeded legumes (e.g. Cajanus) were planted at a spacing of 60 X 40 cm, and those with small size grains (e.g. Medicago sativa and Desmodium) were drilled at 40 cm between rows. Visual inspection for percent ground cover and measurement of biomass yield from a 1 x 1 m quadrat was done after 12 months.

On-Station Experiments

On-station field experiments were conducted at one location in each of the two major agroecological zones in the project area: the Buberuka Highlands and the Central Plateau. The Buberuka Highland site was under bush fallow, and the Central Plateau was cropped with sorghum and sweet potatoes prior to trial initiation. Some pre-trial characteristics of the surface (0-15 cm) soils are presented in Table 1. Methods of analyses were Walkley-Black for organic carbon, Bray 1 for phosphorus, Macro-Kjeldahl for nitrogen and ammonium saturation at pH 7 for exchangeable cations (IITA, 1979).

At both sites, the following leguminous species were tested with and without inoculum: Mucuna spp., Glycine wightii, Canavalia spp., Stylosanthes guianensis, Cajanus cajan, Desmodium intortum spp., Trifolium spp., and Medicago sativa. Each legume was planted on 10 m^2 plots and was grown for five months (April to August 1986) before being incorporated into the soil as green manure. Some of the cover crops (Vetch and Lupin) had flowered and seeded at the time of incorporation. Sowing density was in accordance with ISAR's recommendation above. There were two replications for each species. Growth performance was assessed by visually scoring ground cover on a scale of 1 to 5 (1=less than 5% and 5 = 100% cover) at 3 months after planting (MAP). Quadrat sampling for fresh matter yield was done prior to incorporation. Determination of the nutrient content of dry matter was carried out using standard analytical procedures (described in IITA, 1979). Following incorporation, corn (Zea mays, var. Bamboo) was planted as a test crop. In a related experiment, corn was grown with nitrogen (urea) at different rates (0, 30, 60, 90 and 120 kg/ha) to determine the yield response of corn to N. Nitrogen was split applied with 1/3 at planting and 2/3 at 6 weeks after planting. This trial was replicated at four sites. The N response equation was then used to estimate the fertilizer N equivalents of incorporated legumes.

Multilocation Testing

A field day was organized four months after planting legumes on-station to introduce farmers to cover crops and to select farmer-cooperators for multilocational testing. Thirty farmers participated in the field day, and all of them expressed the need for further testing the legumes at many sites to cover minor agroecological zones in the region. A common remark from farmers in the Central Plateau area was, "We believe the legumes that are growing poorly on this site will do well on our fields." Farmers readily volunteered to assist in multilocational legume testing. There were 11 test sites (Fig. 1). Altitude, rainfall and soil type were used to characterized the sites. Sites 1, 2 and 3 were located in the north where the mean annual rainfall is < 1200 mm, altitude is > 2000 m and soils are derived from granite. Sites 4, 5, 6, 7 and 8 were in the Central Plateau area where rainfall is between 1200 and 1400 mm, altitude is > 2000 m and soils are derived from granite and schists. Sites 9, 10 and 11 were located south of the project area with annual rainfall > 1500 mm, an altitude range of 1500 to 1800 m and soils developed from schists and quartzite. At each test site, Lupin, Vetch, Mucuna and Canavalia were

planted as described above. Medicago sativa was planted only in the northern part of the project area due to lack of adequate seeds. Plot size was 10 m^2 with two replications per site. Biomass yield and ground cover assessments were performed as in the on-station experiment above.

RESULTS AND DISCUSSION

Exploratory Study

Dry matter yields of legume species are shown in Table 2. With the exception of Medicago sativa and Cajanus, species gave high biomass yields and good ground cover. Vetch formed dead mulch during the dry season and reseeded to form fresh ground cover with onset of rains. Biomass yields of Desmodium species were superior to yields of other species. Trifolium repens (white clover) produced low biomass yield, but its prostrate and complete ground cover make it an ideal live-mulch species to control soil erosion. In addition to providing green manure, these herbaceous legumes could prove useful for weed control and soil moisture conservation during fallow.

On-Station Experiments

Fresh matter yields of the herbaceous legumes, grown with and without inoculation in the two major agroecological zones, are shown in Table 3. Fresh matter yields were higher at the Buberuka Highlands than at the Central Plateau site. Lupin and Vetch gave significantly higher yields in the Buberuka Highlands location than at the Central Plateau site. Canavalia and Mucuna performed equally well at both sites. Medicago sativa and Desmodium failed to grow at the Central Plateau site. Inoculation did not significantly influence fresh matter production. Performance differed significantly among legumes for the period over which they were evaluated. Fresh matter yields for Lupin were higher than those for Medicago and Desmodium. Desmodium is a slow starter but, given a growth period of 6 months or more, it can produce dry matter yield of over 1.0 Kg/m^2. This fact was noted in the exploratory trials (Table 2) and was confirmed in another study (not reported here) where, during a period of 7 months, Desmodium, Mucuna and Medicago sativa yielded 2.9, 1.9 and 0.8 kg/m^2 respectively. The disparity in growth of the legumes at the two agroecological zones may be due to altitude and temperature differences between test sites. Apart from these differences, relatively rich soils at the site in the Buberuka Highlands (Table 1) probably favored legume growth.

Using the results from a separate fertilizer study, nitrogen fertilizer equivalents were determined for cover crops grown on-station in the Buberuka Highlands. This location was one of four sites where maize yield was examined as a function of N levels. In regression of maize yield on N levels, the coefficient for the on-station site (dummy variable) was highly significant (99% confidence level) as was the coefficient for N level. A yield response curve for the station site was obtained by incorporating these two parameters:

$$Y_{os} = a + b_1 + b_2N$$

where
Y_{os} = on-station maize yield
a = intercept of equation for site of reference
b_1 = intercept shifter for the station site
b_2 = coefficient of N level for all four sites.

The above model assumes a linear relationship for the range of N applied. Thereafter, an inverse function was used to estimate nitrogen fertilizer equivalent for a given cover crop (NE_c):

$$NE_c = (Y_c - (a + b_1))/b_2$$

where
Y_c = maize yield from a given cover crop.

The NE_c obtained from the preceding equation revealed low to negative N contributions by some legumes that produced high biomass and vigorous growth (Table 4). Other legumes that yielded comparatively low

biomass corresponded to large N contributions. The principle exception to this pattern was Mucuna, which had a high biomass yield (22,300 kg/ha) but resulted in a high N contribution (118.7 kg/ha).

A yield decrease in the first crop after incorporation of legumes as green manure is not unusual. Soil nutrients absorbed during the fallow period and stored in the legume biomass may not mineralize in time to become available to the succeeding crop. The herbaceous legumes tested in this study possess different lignin to N ratios and probably vary in polyphenol content as well. Thus, the rate of decomposition and subsequent release of absorbed and immobilized nutrients is expected to vary among the species (Vallis and Jones, 1973; Palm, 1988).

Decomposition probably was slowed by low environmental temperatures and low soil pH in the Buberuka Highlands. Therefore, two seasons was too short a time to evaluate green manure crops as a long-term source of nutrients supply for maize (Myers, 1982).

In plots where legumes failed or performed poorly, results indicate a possible net mineralization of N and release of other nutrients from existing soil organic matter and residues incorporated into the soil from the natural bush fallow. The N fertilizer equivalent implied that N was the only element affecting maize yield in the green manure plots. It should be noted, however, that other nutrients also contributed to maize yield. The N fertilizer equivalent approach for screening legumes, therefore, should not be used as the sole criterion to judge the efficacy of green manure crops.

As a technology for farmers, these results are disappointing. The average maize yield loss following high biomass legumes compared with maize following cover crops that failed to grow at all was 260 kg/ha. Valuing the maize at the 1986 average local price, this represents a loss of $41.27/ha. This cost is in addition to the cost of not producing a food crop during the season in which the cover crop is grown. The substantial variability in legume nutrient content, decomposition rates and subsequent maize yields suggest that field studies on decomposition and nutrient release patterns of herbaceous legumes be part of the legume screening exercise. The poor performance of legumes at the Central Plateau station site suggests that using starter fertilizer would help legume establishment. Economically, however, applying fertilizer to unmarketable cover crops would not be attractive to most farmers.

Vigorous and rapid lateral growth is an important characteristic of herbaceous legumes for erosion control. In the FSRP area, slopes ranging between 40% and 70% are not uncommon. There is, therefore, a need to identify herbaceous legumes that would rapidly cover the soil to reduce erosion during fallow periods. There were significant ground coverage differences among species (Table 5). In the Buberuka highlands, Lupin, Vetch and Medicago sativa gave 90% to 100% ground cover within three months. At the Central Plateau, Mucuna and Canavalia proved superior to the above. To speed the rate at which complete cover is attained, high seeding rates may be a preferable management strategy.

Nutrient yields of the herbaceous legumes are presented in Table 6. Inoculation with the specific Rhizobium significantly increased N content of the legumes. All legumes except non-inoculated Medicago sativa had more than 2% N. If one could increase legume dry matter yield by using cultural practices such as fertilization, relay cropping to prolong vegetative growth or sowing at high seeding rates, total N input from the legumes could be increased. By inoculating the seeds with the appropriate rhizobia, further gains in N would also be made.

McChlery (1936) suggested supplemental N to aid decomposition of green manure materials having less than 2% N. All the legumes used in this study had greater than 2% N, thus making such N addition unnecessary. However, for certain crops, particularly cereals, external sources of N in the form of inorganic fertilization may still be needed to optimize the food crop yield (Herridge, 1982; Greenland, 1984). Accumulation of other nutrients (Ca, Mg, K and P) by legumes during the fallow period differed among species. For instance, Canavalia immobilized more Ca than all other legumes; Desmodium, more Mg; Lupin, more K; and Dolichos, more P. Regarding soil amelioration, legume fallows are generally preferred due to their exceptional ability to extract unavailable soil P (Rattray and Ellis, 1952; Russel, 1950) and N fixation.

Turning fresh matter into the soil slowly releases immobilized nutrients to subsequent food crops via decomposition. To improve the efficiency of nutrient uptake by food crops, it is important to synchronize the pattern of nutrient release by the incorporated materials with the nutrient requirements of the food crops. Again, Table 6 shows that the herbaceous legumes have different nutrient contents. Achieving a balanced soil fertility may require a mixture of legumes instead of using a monocrop fallow. Mixing legumes with different biomass yields, growth habits and decomposition rates allows farmers to choose the combination of properties best suited to his or her constraints and objectives.

Multilocational Testing

Mean fresh matter yields and ground cover of legumes in 3 zones (North, Central and South) are presented in Fig. 2 and 3, respectively. The high coefficient of variation (CV) values associated with the performance of the legumes give credence to the farmers' observation that the growth of the legumes is so variable that it is difficult or even dangerous to recommend a cover crop based on good growth at a few locations in the project area. This also supports the idea of growing the legumes in mixtures instead of monocrops. The 11 sites used for the multilocational screening may still not be adequate to cover all the microagroecological zones that may exist in the FSRP zone, but it does raise our level of confidence in making some preliminary recommendations.

Our research indicates that Lupin, Mucuna and Vetch are good cover crops for the North; Vetch and Lupin are suitable for the Central; and Lupin and Mucuna are good for the South of the FSRP area (Fig. 2). However, the results in Table 3 indicate that Lupin in the Central Plateau site in the South did poorly when compared to Canavalia. The reason is that, for the multilocational testing in the South, Lupin was planted on a valley-land that is a relatively rich soil compared to the Central Plateau soil characterized in Table 1. This again emphasizes the advantage of starting the herbaceous legumes on relatively fertile soils.

The relative performance of ground cover seems to follow the same pattern as that of fresh matter yield. By sowing Mucuna and Canavalia at high densities, quick soil cover can be ensured. To arrive at a realistic choice of legumes for agroecological zones, selection criteria are proposed that combine fresh matter yield and ground cover with nutrient content of the leguminous species.

Selection Criteria

Agronomically, the optimal legume for a given region in the long term would have the best combination of high vegetative growth and nutrient yield and quick soil coverage to check erosion and control weeds. These two characteristics can be combined in a general empirical equation that gives a legume's productivity value (PV) as follows:

$$PV = f(DM, n_1, n_2, ..., n_i, C) \qquad (1)$$

where:
DM = biomass yield (kg/m2 dry weight),
n_i = concentration of a given nutrient (%) in the plant tissue, C = ground cover based on a selected rating.

The form of this equation used in this study was

$$PV = DM * (N + P + K + Ca + Mg) + C \qquad (2)$$

Accordingly, recommended species for a given location will have high PVs. Applying equation 2 to the present study, the following legumes, in order of preference, are tentatively recommended for the agroecological zones recognized in the FSRP area: In the North, Canavalia (PV = 13.6) and Lupin (PV = 12.9); in the Central zone, Vetch (PV = 10.4) and Lupin; and in the South, Mucuna (PV = 13.1). On relatively rich valley soils in the South, Lupin does reasonably well. Canavalia's performance in the South, especially its growth habit, is good enough to warrant consideration of its potential for that region.

The simplified PV analysis used in this study assumes that all nutrients measured are equally important for determining crop performance. In reality, however, crops differ in their nutrient requirements. The above statement also holds true for importance of ground cover due to slope. Thus, research to determine appropriate coefficients for each nutrient and ground cover rate is needed to better express their relative importance by crop and topography. For example, one PV equation could be developed for cereals on steep slopes and another for tubers on flat lands.

The advantages of sowing the recommended legumes in mixtures at all sites should be reiterated, especially in view of the significant site-species interactions. Although not yet experimentally verified, general observation in the field also suggests possible species-season interaction, further supporting the rationale for sowing mixed legume species similar to the practice followed by local farmers for bean cultivation.

CONCLUSION

The experience gained from this study suggests that initial moderate fertilization, extended growing periods, high seeding rate and mixtures of legumes are helpful for achieving high productivity of herbaceous legumes. Mixtures of legumes in particular give farmers both flexibility and insurance. In the Rwandan highlands, however, both fertilizer application and prolonged vegetative growth may not be acceptable practices due to the acute shortage of arable land and capital in the region.

A management strategy that might facilitate widespread utilization of herbaceous legumes is to relay crop the legumes with a cereal such as maize or sorghum planted with modest applications of P and N.

Maize in the region has a growth cycle of about 28 weeks. Relay seeding the legumes into the maize at 8 weeks after planting will allow the legumes to grow for 20 weeks before the maize is harvested. The 20-week overlap for maize and the legumes, in addition to another 8-week "recuperation" period usually observed between growing seasons, would result in a total of 28 weeks to permit sufficient growth of the legumes. The compatibility of several associations and their acceptability to farmers are being investigated. This includes using high seeding rates and mixtures of some of the legumes. Finally, studies on decomposition of the herbaceous legumes should precede extension of their use on farmers' fields.

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Table 1. Some characteristics of surface (0-15 cm) soils of experimental fields in the two macro agroecological zones.

Characteristic	Buberuka Highland	Central Plateau
pH - water	4.8	4.3
Org. C(% O)	3.5	1.4
Total N (%)	0.38	0.15
Ca (me/100 g)	7.0	1.62
K (me/100 g)	0.30	0.34
Mg (me/100 g)	3.46	0.67
Na (me/100 g)	0.05	0.03
CEC (me/100 g)	22.81	15.7
Clay (%)	60.8	36.1

Table 2. Dry matter yield of some herbaceous legumes during exploratory surveys at 12 months after planting.

Crop	Dry matter[1]	Remarks
	Kg/m^2	
Vetch spp.	0.950 (0.52)	Very good ground cover, high biomass.
Desmodium uncinatum	1.400 (0.98)	Very good ground cover, high biomass and bushy growth habit
Desmodium intortum	0.850 (0.01)	Very good ground cover, high biomass and bushy growth habit
Stylosanthes spp.	0.980 (0.03)	Very good ground cover, high biomass
Cajanus cajan	0.224 (0.06)	Fairly good ground cover, low biomass
Medicago sativa	0.180 (0.02)	Fairly good ground cover, low biomass
Trifolium repens	0.372 (0.01)	Excellent ground cover, low biomass, good for living mulch
Trifolium spp.	1.530 (0.43)	Good ground cover, high biomass
Desmodium australine	1.120 (0.45)	Good ground cover, high biomass
Control (weed/grass)	1.080 (0.08)	Good ground cover, high biomass

[1] Standard deviation is given in parentheses.

Table 3. Fresh matter yields (Kg/m^2) of herbaceous legumes in two major ecozones at 4 months after planting.

Legume	Buberuka		Central Plateau	
	Kg\m^2			
Lupin	3.60	3.60	0.18	0.24
Medicago	0.80	0.58	0.00	0.00
Desmodium	0.60	0.70	0.00	0.00
Vetch	2.60	1.90	0.00	0.00
Cajanus	0.76	0.70	0.54	0.40
Mucuna	1.66	2.80	2.00	1.60
Dolichos	2.40	1.40	1.60	0.96
Canavalia	3.16	4.20	3.90	4.10

[1] + = inoculated; - = non-inoculated

LSD (0.05):
Between leguminous species at same site = 0.36
Between same legumes at different sites = 0.52

Table 4. Nitrogen fertilizer equivalents of legumes.

Legume	Maize yield	N fertilizer equivalent
crop	Kg/ha	
Desmodium	2187	-41.0
Vetch	2312	-19.7
Lupin	2437	1.5
Medicago	2500	12.3
Glycine	2562	22.8
Canavalia	2575	25.1
Dolichos	2625	33.6
Centrosema	2937	86.7
Trifolium	2937	86.7
Stylosanthes	3062	108.0
Mucuna	3125	118.7
Cajanus	3262	142.1

Table 5. Ground cover/plant vigour ratings of herbaceous legumes at 3 months after planting.

Legume	Buberuka	Central Plateau
crop	----------score[1]----------	
Trifolium repens	3.0	1.0
Canavalia	3.0	5.0
Lupin	5.0	1.0
Dolichos	2.0	3.5
Centrosema	1.0	1.0
Stylosanthes	2.0	1.0
Medicago	4.5	1.0
Mucuna	3.0	5.0
Cajanus	3.0	3.0
Vetch	5.0	1.0
Desmodium	3.0	1.0
Glycine	2.0	1.0

[1]Scoring 5 = 100% ground coverage/very vigorous growth.
1 = < 5% ground coverage/insignificant growth.

LSD (0.05):
Between same legume crop at different sites: 0.44
Between legumes at same site: 0.31.

Table 6. Nutrient content of herbaceous legumes.

Legume	N(+)[1]	N(-)	Ca	Mg	K	P
crop	----------%----------					
Medicago	2.50	1.87	2.95	0.56	1.26	0.11
Vetch	3.32	3.04	1.74	0.17	1.49	0.21
Cajanus	3.11	2.26	2.11	0.30	1.64	0.27
Lupin	2.73	2.44	1.58	0.36	1.82	0.17
Dolichos	3.09	2.60	1.89	0.65	1.75	0.31
Canavalia	4.10	3.43	3.00	0.65	1.51	0.24
Desmodium	3.76	3.36	1.71	0.76	0.90	0.17
Mucuna	3.71	3.18	2.05	0.46	1.53	0.29

[1] N(+) = inoculated; N(-) = non-inoculated

LSD (0.05):
Between inoculated treatments for N : 0.27
Between legume crops for Ca: 0.55
Between legume crops for Mg: 0.18
Between legume crops for K: 0.44
Between legume crops for P: 0.04

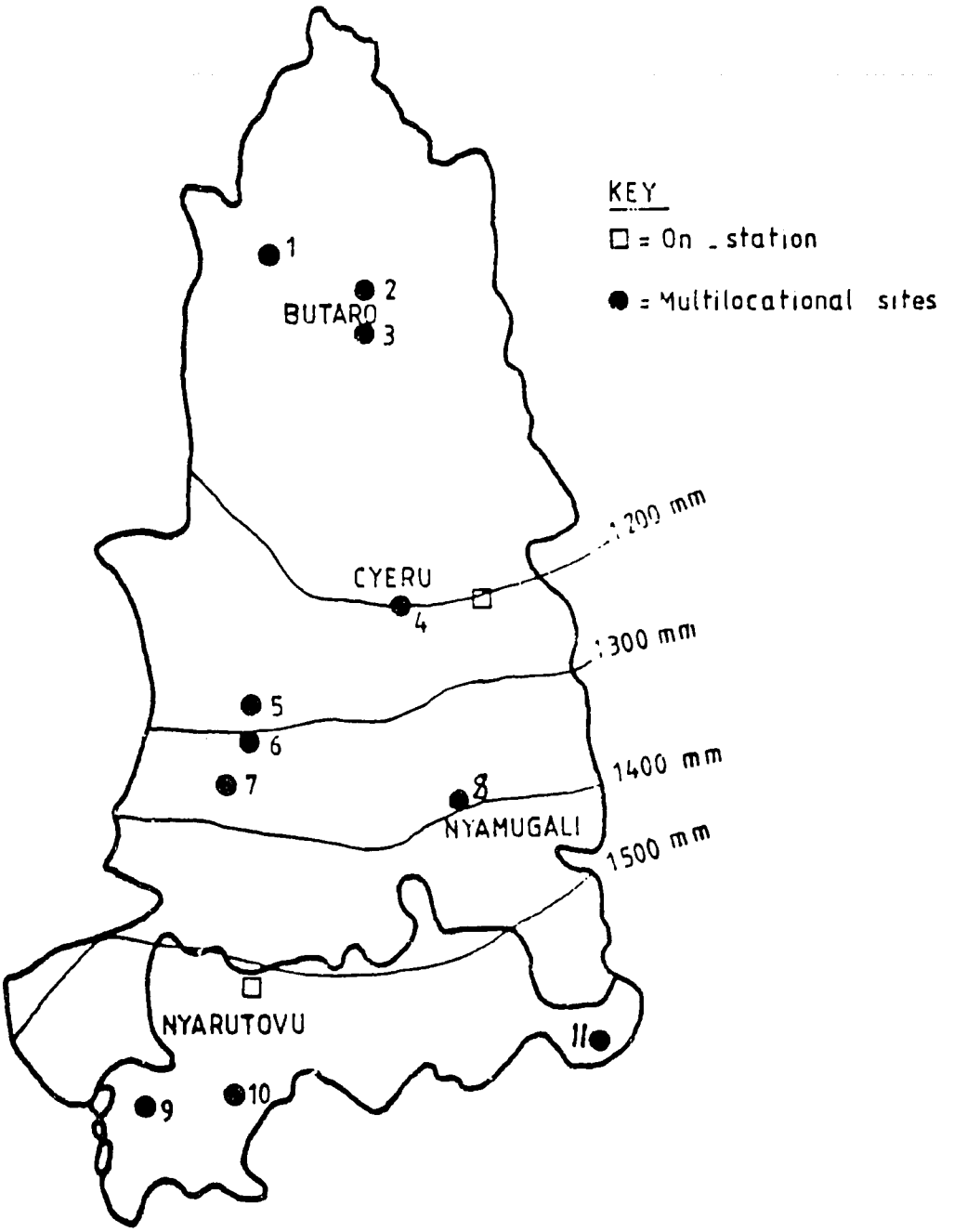

Fig. 1. Map of the FSRP area showing sites for multilocational testing and on-station plots. Scale = 1/290,000

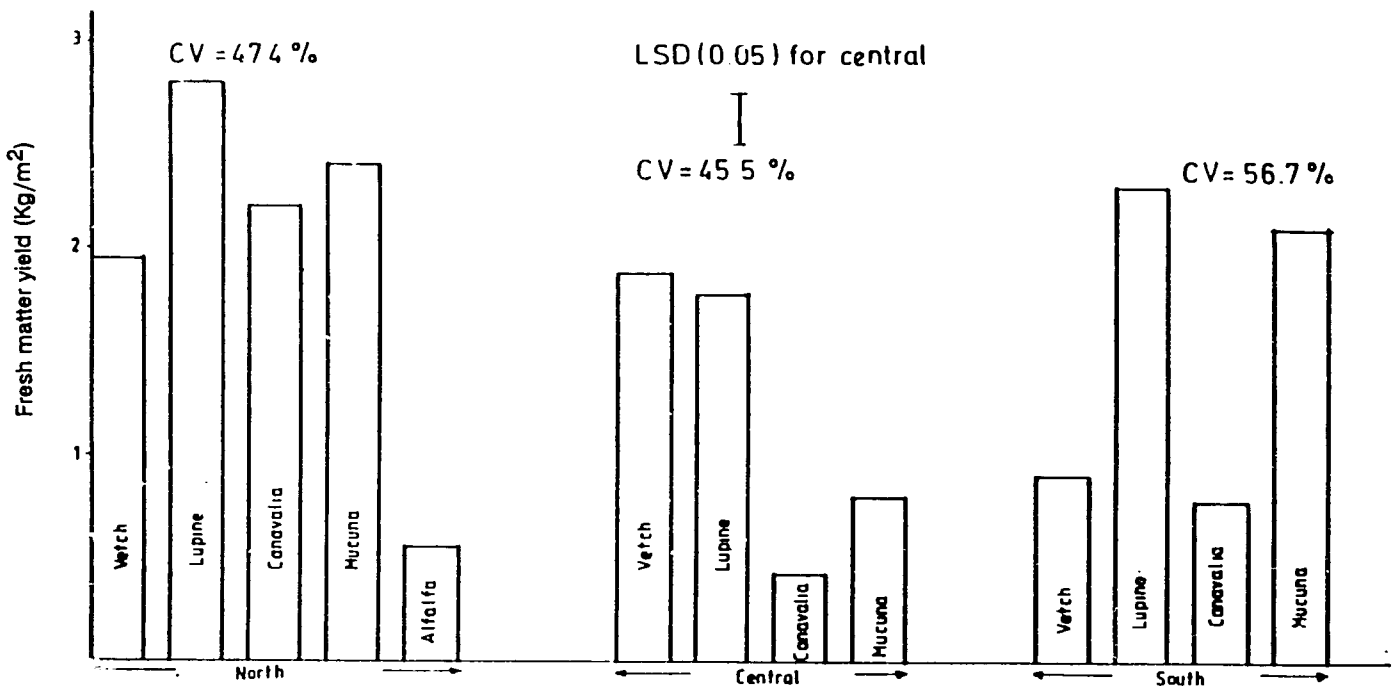

Fig. 2. Fresh matter yields of herbaceous legumes at multilocational sites (see fig. 1).

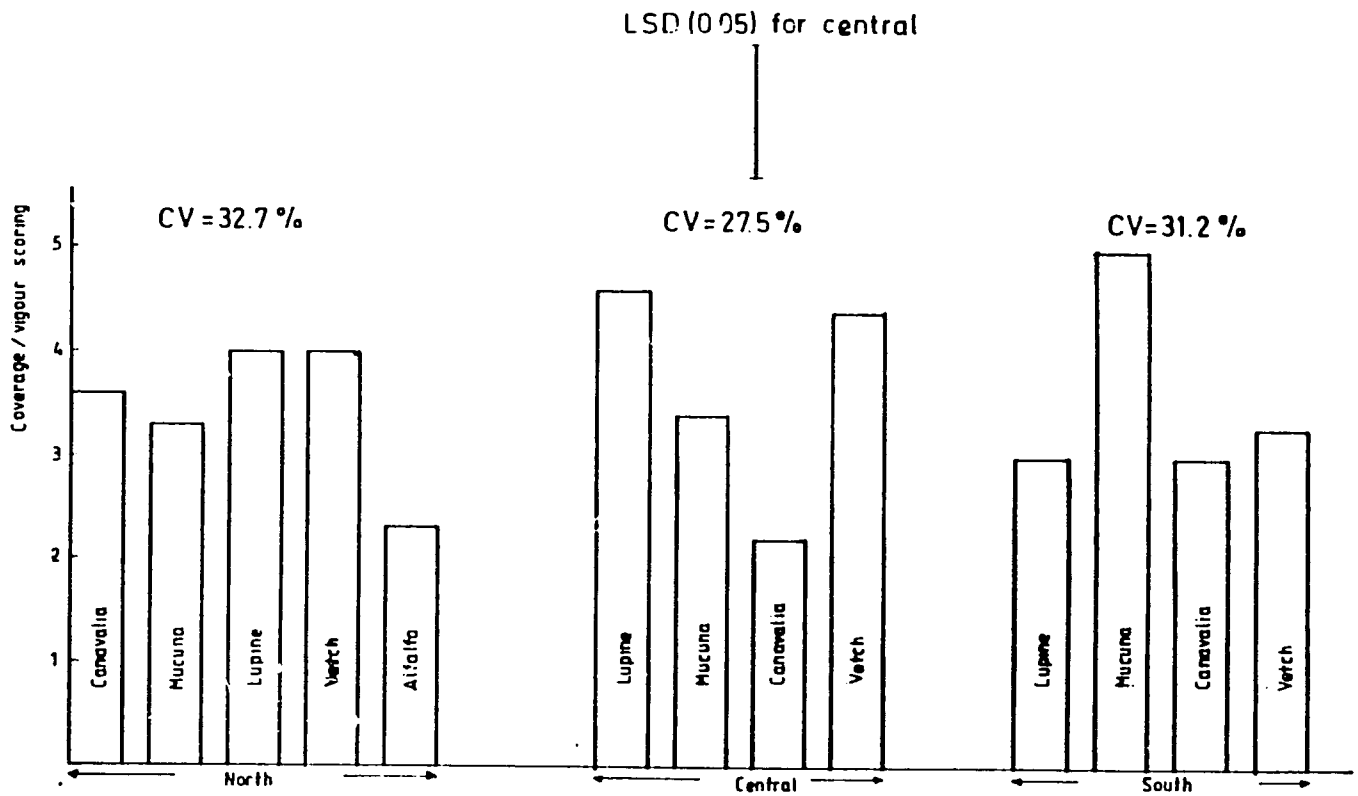

Fig. 3. Ground coverage/vigour of herbaceous legumes at multilocational sites (see fig. 1).