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Use of wheat straw, soybean trash and nitrogen fertiliser for maize production in the Kenyan highlands

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ABSTRACT

Making best use of available crop residues is an important component of integrated nutrient management. A field study was conducted over two seasons (1997 and 1998) in Kenya that examined use of wheat straw, soybean trash and nitrogen fertiliser as nutrient inputs for maize (*Zea mays* L.) production. The organic inputs were applied at the rate of 2 t ha^{-1} per season and urea was added at rates of 0, 20, 40, 80 and 100 kg N ha^{-1} in an incomplete factorial treatment structure that also included a complete control (no inputs) and 80 kg N ha^{-1} as urea without organic inputs. Maize grain yield ranged between 751 and 6836 kg ha^{-1} with lowest yields observed in the treatment receiving wheat straw alone and higher yields associated with soybean residue incorporation and during the second, wetter growing season. The 1998 crop benefited from more favourable rainfall, providing grain yield increase of 141% above control treatment as a result of combining 2 t ha^{-1} soybean trash and 100 kg N ha^{-1} urea. The generally high yields from soybean trash are explained in terms of its higher quality, faster decomposition and nutrient release compared to the lower quality wheat straw. A positive effect in increases of soil pH, C, N and P status as a result of cumulative use of crop residues was observed. Larger yields were obtained when organic and inorganic inputs were applied to soils, particularly when soil moistue was adequate and the organic inputs higher in mineralisable nutrients. Early indications of additional longer-term benefits through soil quality improvement were also measured. These findings suggest that better use may be made of crop residues than the burning following harvest as is currently practiced by many farmers in this area of western Kenya.

Key Words: Crop residues, East African highlands, integrated nutrient management, smallhold farming systems, soil fertility, urea

RÉSUMÉ

La bonne utilisation de résidus des cultures disponibles est une composante importante de la gestion intégrée des éléments nutritifs. Une étude en champs a été conduite pendant deux saisons (1997 et 1998) au Kenya pour examiner l'utilisation de la paille de blé, les fanes de soja et l'engrais azoté comme intrants pour la production du maïs (*Zea mays* L.). Les intrants organiques étaient appliqués à un taux de 2 t ha^{-1} par saison et l'urée était ajoutée à des taux de 0, 20, 40, 80 et 100 kg N ha dans une structure de traitement factoriel incomplet qui comprenait aussi un contrôle complet (pas d'intrant) et 80 kg N comme urée sans intrant organique. Le rendement en grains du maïs variait entre 751 et 6856 kg ha^{-1}, le plus faible rendement était observé dans le traitement ayant reçu la paille de blé seule et les plus haut rendements étaient associés avec l'incorporation des résidus de soja durant la seconde saison pluvieuse. La culture de la saison 1998 a bénéficie des pluies favorables aboutissant à une augmentation de rendement en grains de 141% plus que le traitement témoin résultant de la combinaison de 2 t ha^{-1} de fanes de soja et de 100 kg N ha^{-1} d'urée. Les rendements générallement élevés obtenus à partir des fanes de soja sont expliqués en termes de qualité, de décomposition plus rapide et de libération des éléments nutritifs en comparaison de la pauvre qualité de la paille de blé. Un effet positif dans l'augmentation du pH du sol, de l'état du C, N et P résultant de l'utilisation cumulative des résidus des cultures a été observé. Des rendements élevés étaient obtenus quand les intrants organiques, et inorganiques étaient appliqués aux sols, en particulier quant l'humidité du sol était adéquate et les intrants organiques élevés en éléments minéralisables. Des indications précoces des bénéfices additionels à long-terme via l'amélioration de la qualité du sol ont été aussi mésurées. Ces résultats suggèrent que la meilleure utilisation peut être faite des résidus de cultures plus que le brélage après recolte comme il est présentement pratiqué par la majorité des agriculteurs dans cette région ouest du Kenya.

Mots Clés: Résidus de culture, hautes terres de l'Afrique de l'Est, gestion intégrée des éléments nutritifs, systèmes de cultures des petits fermiers, fertilité du sol, urée

Introduction

Many countries in sub-Saharan Africa continue to require increasing amounts of food aid (World Bank, 1996). As a result, donor countries question their abilities to meet the growing food deficits. Some reasons for this situation include frequent droughts, political unrest, rapid population growth, and unaffordale costs of external farm inputs while increased food supplies are needed to feed the growing populations in Africa. This requirement has contributed to the abandonment of traditional methods of land fallow that were important in soil fertility conservation. Many croplands are now continuously cultivated with little nutrient additions (Makken, 1993), resulting in diminishing productivity and declining per capita food production (Woomer and Muchena, 1996; Woomer *et al.*, 1997). A fundamental constraint to crop production in African smallholder agriculture is soil nutrient depletion. Sanchez *et al.* (1997) reported annual losses of 660, 75 and 450 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K), respectively, during the past three decades, in about 200 million hectares cultivated in 37 African countries. Apart from nutrient mining from continuous cultivation practices, nutrient depletion also results from erosion, leaching and dentrification. Smaling *et al.* (1997) estimated that farming systems in the East African Highlands lose nutrients at rates of 130 kg N, 5 kg P and 25 kg K ha^{-1} y^{-1}.

Past studies in western Kenya strongly suggest that nitrogen and phosphorus are the two most widespread nutrient limitations to crop growth (FURP, 1994; Shepherd *et al*., 1995; Woomer *et al*., 1997). Many farmers in western Kenya are aware of the need to apply N and P fertilisers to increase crop yields, but the costs of fertilisers are prohibitive. However, alternative options for soil fertility improvement have been identified, and are better suited to smallhold farmers'conditions. One option is the use of organic resources such as manure and composts and the return of crop residues and tree prunings to soils (Probert *et al.*, 1992; Palm, 1995). The combination of crop residues and N and P fertilisers improves the availability of these two nutrients, particularly when low quality organic resources, such as maize stover, or wheat straw are retained (Palm *et al.*, 1997). Agroforestry systems enhance nutrient recycling as short-term fallows. The fast growing nitrogen-fixing *Sesbania sesban* offers particular promise in western Kenya (Buresh *et al.*, 1997).

Limitations exist regarding the use of organic resources as a sole means to improve soil fertility. In central Kenya, crop residues are mainly fed to cattle (Ikombo *et al.*, 1994). But in Uasin Gishu district, crop residues (4 to 6 t ha^{-1} per season) are burnt to facilitate land clearing and ploughing for the subsequent crop (Muasya, 1995). The quality of organic resources targeted for soil fertility improvement is highly variable (Probert *et al.*, 1992). This quality factor plays an important role in the decomposition and nutrient release patterns from organic materials. The materials with carbon to nitrogen ratios above 25 decompose and release nutrients slowly, and materials with low lignin and polyphenolic contents decompose more quickly (Palm *et al.*, 1997). This paper reports findings in which high (soybean trash) and low (wheat straw) quality crop residues were studied in combination with nitrogen fertiliser to enhance N availability and nutrient uptake by maize.

Materials and methods

Chepkoilel site. A field experiment was conducted at the Chepkoilel Campus of Moi University, Uasin Gishu District, Kenya. The site is located 35º18' E and 0º30' N at an elevation of 2140 m above sea level. Precipitation ranges from 900 to 1300 mm with an annual mean of 1124 mm. This rainfall occurs during one long season from March to September. Mean annual temperature is 23ºC with a minimum of 10ºC. The soils are underlain by tertiary volcanic rocks (phenolites) and murram, acidic (pH 4.5-5.0), dark red, friable and classified as Rhodic Ferralsols (FAO/UNESCO) or oxisols (USDA). Uasin Gishu lies in a highland plateau, which forms a large wheat and maize growing area in Kenya, mainly within the agroecozone known as the wheat, barley zone (Jaetzold and Schmidt, 1983).

Maize field experiment. Two different crop residues were tested in the field experiment; wheat straw and soybean trash. These organic materials differ in nutrient status (Table 1) and are available in large quantities (2-7 t ha^{-1}) following harvests (Muasya, 1995).

Table 1. Chemical characteristics of crop residues in a field trial at Chepkoilel, Kenya 1997/98

Material	% dry matter					
	N	P	Ca	Mg	Lignin	Polyphenolics
Wheat straw	0.67	0.09	0.18	0.10	8.63	1.11
Soybean trash	1.07	0.20	1.75	0.20	9.31	1.17

Treatments consisted of sun-dried and chopped (2 to 4 cm) wheat straw and soybean trash applications at a uniform rate of 2 t ha^{-1} for each material. Fertiliser N was combined with these organics at the rates of 0, 20, 40, 80 and 100 kg N ha^{-1} as urea. These treatments were applied at maize planting, first in March 1997, and were repeated in the following season (March 1998). To eliminate P and K limitations, 100 kg P ha^{-1} as single superphosphate and 100 kg K ha^{-1} as muriate of potash were applied. All inputs were incorporated into the seedbed by hand tillage. The experiment was arranged as a randomised complete block with 4 replicates. Starter N for all nitrogen treatments was applied at 20 kg N ha^{-1} at planting.

Two maize seeds (hybrid 614D) were planted into each hole of about 10 cm depth, spaced at 30 cm within and 75 cm between rows. Plots were 6 m x 3.75 m, accommodating 5 rows per plot. Plants were thinned to one per "hill" four weeks after planting, resulting in a maize population of 4.4 plants m^{-2}. At this stage, nitrogen was topdressed along maize rows as urea. Weeding was done by hoe and insects were controlled using depterex granules. In 1998, maize heights were measured from 6 plants per plot biweekly. At harvest, cobs and stover were separated. Sub-samples of these components were dried (40ºC) and weighed to obtain yield measurements. The samples were ground (20 mesh), analysed for N, P and K (Okalebo *et al.,* 1993) and nutrient uptake and removal by each treatment calculated.

Soil sampling, preparation and anlysis. Before treatment application in 1997, surface (0 - 20 cm) soils were sampled at random. This field had been under continuous wheat cropping for over 5 years with modest diammonium phosphate applications. Thirty auger borings were made and the soils from these sampling points were bulked, mixed thoroughly and a 1.0 kg sub-sample air-dried and sieved (2 mm) for laboratory analysis. At the end of the second consecutive maize cropping season (October 1998), soils (0-20 cm) were obtained from each plot by bulking, mixing and sub-sampling 9 cores made at random across each plot. All soil samples were analysed for pH (2.5:1 H_2O), total carbon and nitrogen and extractable phosphorus (Olsen) following the methods outlined in Okalebo *et al.* (1993).

Results and discussion

Maize growth. Seedling establishment at two weeks after planting was uniform across all plots during both years of maize cropping at Chepkoilel. This was attributed to favourable soil moisture necessary for seed germination, emergence and establishment. Uniform emergence of seedlings also resulted from use of quality seed in this study.

In Table 2, as expected from good rainfall of 1998, maize heights increased to 295 cm 112 days after planting. During early growth, the roots from young plants were likely not fully developed to exploit nutrients from the larger soil volume. However, from 44 days after planting until maize maturity, heights increased with N level but soybean trash-N combinations provided taller plants than wheat straw-N combinations (Table 2). The comparison of soybean-N incorporation and wheat straw-N incorporation is also presented, combining the heights for each organic input source across all N application rates. It is possible that maize obtained an 'extra' supply of N in plots receiving soybean trash with a higher N content (Table 1). In addition, N release in soils may have been favoured by rapid decomposition of the legume residue compared to the more recalcitrant cereal residue (Palm *et al.,* 1997).

Table 2. Effect of organic and inorganic nutrient sources on maize height increases in 1998 season at Chepkoilel

Treatment[a]	Maize height (cm) days after planting						
	30	44	56	70	84	98	112
Control	32	44	56	70	84	98	112

80N	33	56	81	122	157	200	237
WS + 0N	34	58	85	126	172	213	229
WS + 20N	32	56	81	132	171	208	223
WS + 40N	27	69	93	113	155	190	239
WS + 80N	36	62	90	117	159	228	263
WS + 100N	35	61	88	119	155	197	266
SYT + 0N	34	59	92	122	173	216	267
SYT + 20N	33	61	89	121	161	202	223
SYT + 40N	34	57	85	134	179	209	244
SYT + 80N	36	64	96	139	178	233	280
SYT + 100N	38	70	102	125	166	233	295

[a]WS = Wheat straw, SYT = Soybean trash
N = Nitrogen applied as urea at 0,20,40,80 and 100 kg N ha^{-1}
Heights are the means from 4 replicates for each treatment for each date of measurement

Figure 1

Maize yield. In 1997, grain yield ranged from 875 to 1876 kg ha^{-1} while stover yield was from 3696 to 6028 kg ha^{-1} (Table 3). This grain yield is rather low for the croplands of Uasin Gishu District under the average levels of nutrient inputs of 60 kg N ha^{-1} plus 22 kg P ha^{-1} (Muasya, 1995). The low yield is partly explained in terms of low and poor rainfall distribution from August to September. Total rainfall received in this period at Chepkoilel in 1997 and 1998 was 232 and 380 mm, respectively, and this low rainfall did not favour soil moisture and nutrient availability, resulting in sub-optimal maize nutrition, grain fill and low yield. Nevertheless, many treatments demonstrated significant increases in maize yield ($P<0.05$), particularly from 2 t ha^{-1} wheat straw and soybean trash combined with fertiliser N above 80 kg N ha^{-1} (Table 3). Grain yields for 1998 were between 2832 and 6836 kg ha^{-1}, whereas stover yields ranged between 10390 and 13950 kg ha^{-1} (Table 3). Favourable rainfall and its distribution in that year contributed to larger maize yields. Again higher yields were obtained from soybean trash and N fertiliser applications above 80 kg ha^{-1}. This response may be due to an increased N input of about 20 kg N ha^{-1} from soybean trash compared to that of only 13 kg N ha^{-1} from wheat straw (Table 1). Past work has identified a nitrogen limitation in Chepkoilel soils. In the present study, high maize yields were found from fertiliser N addition above at 80 kg N ha^{-1} and from soybean trash combined with nitrogen above 80 kg ha^{-1} (Fig. 2) in two seasons.

Table 3. Effect of combined crop residues and nitrogen fertiliser on maize yield (kg ha^{-1}) in Chepkoilel soils

Treatmenta	1997	1998

	Grain	Stover	Total	Grain	Stover	Total
Control	875	4461	5336	2832	10390	13222
80N	1016	5600	6616	4883	13000	17883
WS + 0N	960	3696	4656	2051	10470	12521
WS + 20N	1321	4923	6144	2930	10850	13780
WS + 40N	1304	6028	7332	3223	10560	13783
WS + 80N	1666	5977	7643	4785	12490	17275
WS +100N	1677	6661	8338	5469	12390	17859
SYT + 0N	751	4300	5051	2832	11960	14792
SYT + 20N	1465	5840	7305	2500	11930	14430
SYT + 40N	1444	5778	7221	3711	13400	17111
SYT + 80N	1500	5704	7204	5567	13500	19067
SYT + 100N	1876	5811	7687	6836	13950	20786
LSD (P = 0.05)	555	1681	1827	1030	NS	4262

aWS = Wheat straw, SYT = Soybean trash
N = Nitrogen applied as urea at 0,20,40,80 and 100 kg N ha^{-1}

Total uptake of nitrogen and phosphorus. The total nitrogen accumulated in grain and stover obtained at harvest in 1997 ranged from 27 to 58 kg N ha^{-1}, while the phosphorus uptake was 3.9 to 7.1 kg P ha^{-1} (Table 4). These rather low N and P uptake figures are implied from low maize yields. However, some treatments resulted in significantly greater N and P uptakes in the grain plus stover. Wheat straw at 2 t ha^{-1} with N combinations above 40 kg ha^{-1} were associated with larger N and P accumulations. These nutrients may have been released from the wheat straw slowly, extending availability for uptake compared to soybean trash.

Total uptake of N by maize in 1998 was between 53 and 130 kg N ha^{-1} while the phosphorus accumulated in the two components ranged from 4.3 to 8.7 kg P ha^{-1} (Table 4). Higher N and P accumulation in this second season is attributed to favourable rainfall and increased maize yields. Again, N and P accumulation increased with levels of fertiliser N incorporated with organic residues. Figure 3 shows the N accumulation in the treatments. Less N uptake from straw may be indicative of N immobilisation in soils, where soil microrganisms assimilate nitrogen and other nutrients from the residues, reducing their availability to plant roots (Palm *et al.,* 1997).

Table 4. Effects of organic and inorganic nutrient inputs on total uptake of nitrogen and phosphorus (kg ha^{-1}) by maize at Chepkoilel, Kenya

Treatment	1997		1998	
	Total N Uptake	Total P uptake	Total N uptake	Total P uptake
Control	33.9	4.08	69	5.40

80N	42.9	4.35	85	5.80
WS + 0N	29.4	3.88	69	4.80
WS + 20N	39.1	4.29	104	5.30
WS + 40N	57.5	4.89	64	5.60
WS + 80N	53.4	6.51	103	6.60
WS + 100N	50.9	6.29	110	7.10
SYT + 0N	27.2	4.02	53	4.30
SYT + 20N	39.1	5.26	76	5.40
SYT + 40N	48.3	4.70	80	5.60
SYT + 80N	44.4	4.73	111	7.70
SYT + 100N	58.3	7.08	130	8.70
LSD (P0.05)	17.9	1.82	42	2.10

[a]WS = Wheat straw, SYT = Soybean trash
N = Nitrogen applied as urea at 0,20,40,80 and 100 kg N ha^{-1}

Changes in soil properties. Table 5 summarises data for soil pH, C, N and available P obtained in surface (0-20 cm) soils sampled before application of treatments in March 1997 and soils obtained soon after harvesting the second maize crop in October 1998. There were positive changes from organic inputs to increase the levels of these four parameters in soils. Marked increases were realised in N and P levels. These are due to their accumulation from consecutive organic and mineral nutrient additions made in 1997 and 1998 cropping seasons. High Olsen P levels possibly occurred from an initial blanket application of single superphosphate at 100 kg P ha^{-1}. Additional P is likely to have originated from the decay and release of the organically-bound P held in organic materials applied as previously described by Russell (1973).

Table 5. Changes in soil (0-20 cm) properties as influenced by cumulative incorporation of crop residues and urea- N at Chepkoilel, Kenya during two seasons of maize cropping

Treatment	Soil parameter			
	pH (H20)	Total C (%)	Total N (%)	Olsen P (ppm)
At maize harvest (October 1998)				
Control (no inputs)	5.10	1.63	0.50	8.6
80 kg N as urea	5.10	1.21	0.62	9.0
Wheat straw + Na	5.10	1.69	0.65	12.3
Soybean trash + N	5.13	1.71	0.87	12.3
Initial conditions (March 1997)	4.85	1.30	0.11	3.9

[a]Wheat straw and soybean trash data include all treatments receiving urea at 0, 20, 40, 80 and 100 kg N ha^{-1}

This study has demonstrated the positive effect of incorporating crop residues with N fertiliser into the seedbed to improve their decomposition and nutrient release characteristics. The two forms of residues tested (wheat straw and soybean trash) were each applied at a uniform rate of 2 t ha^{-1}. It is quite feasible that this rate of residue be retained in cropland even while alternative requirements (e.g. fuel, feed) are also being met (Table 3). Comparisons of different rates of residue are suggested to obtain responses to both residues and N fertiliser rates. Organic matter fractionation needs to be done after cropping to determine the dynamics of important labile fractions. Investigations of the economics of combined organic and mineral nutrient sources will provide useful information on crop residue management.

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