**Supplementing grass-based cattle feeds with legume leaves and its effects on manure quality and value as a soil improver for an Anthropic Ferralsol in Rwanda**

Marguerite Mukangango1,2\*, Jean Nduwamungu2, Francois Xavier Naramabuye2, Gert Nyberg3, Sigrun Dahlin1

1Department of Soil and Environment, Swedish University of Agricultural Sciences, P.O. Box 7024, SE-75007 Uppsala, Sweden.

2University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine, P.O. Box 117 Butare, Rwanda

3Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE-90183 Umeå, Sweden.

\*Corresponding author, E-mail: marguerite.mukangango@slu.se; [mukangango2@gmail.com](mailto:mukangango2@gmail.com).

**Supplementary material:**

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Table S1. Response of soil total exchangeable acidity (TEA (cmolckg-1)), Exchangeable aluminum (Al3+ (cmolckg-1)) and pHH2O to the application of manure derived from grass diet only, Acacia angustissima supplement to grass basal feed and NPK fertilizer

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Baseline | | | Season1 | | | Season2 | | | Season3 | | | Season4 | | |
| **Treatment** | | **pH** | **TEA** | **Al3+** | **pH** | **TEA** | **Al3+** | **pH** | **TEA** | **Al3+** | **pH** | **TEA** | **Al3+** | **pH** | **TEA** | **Al3+** |
| Lime | Manure | 4.2a | 4.1a | 2.8a | 4.4ab | 3.2b | 2.7a | 4.7a | 2.9bc | 2.2c | 4a | 2.6c | 1.9b | 5.2a | 2.3c | 1.7b |
|  | NPK | 4.5a | 4.1a | 2.8a | 4.5a | 3.5ab | 2.6a | 4.9a | 2.8c | 2.3bc | 4.9a | 2.5c | 1.9b | 5.2a | 2.5c | 1.7b |
|  | Non-fertiliser | 4.3a | 4.1a | 2.7a | 4.4ab | 3.5ab | 2.7a | 4.9a | 2.7c | 2.2bc | 4.9a | 2.6bc | 1.7b | 5.1a | 2.4c | 1.7b |
| Non-lime | Manure | 4.3a | 4.0a | 2.8a | 4.3ab | 3.7a | 2.9a | 4.5ab | 3.1abc | 2.4abc | 4.6a | 2.8bc | 2.1b | 5.1a | 2.8bc | 1.9b |
|  | NPK | 4.3a | 4.1a | 2.9a | 4.3ab | 3.6ab | 3a | 4.4ab | 3.4ab | 2.8ab | 4.4ab | 3.3ab | 2.9a | 4.5b | 3.3ab | 2.9a |
|  | Non-fertiliser | 4.1a | 4.1a | 2.9a | 4.1b | 3.8a | 3.2a | 4.1b | 3.5a | 2.9a | 4.1b | 3.5a | 3.0a | 4.1b | 3.7a | 3.2a |
|  | **Main effect (prob>P)** | | | | | | | | | | | | | | | |
|  | Lime | 0.2717 | 0.8744 | 0.4945 | 0.0071 | 0.0075 | 0.04 | 0.0002 | <.0001 | 0.0002 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
|  | Fertiliser | 0.1436 | 0.4145 | 0.9757 | 0.3284 | 0.4434 | 0.6378 | 0.5578 | 0.9603 | 0.0603 | 0.038 | 0.0479 | 0.0263 | <.0001 | 0.0106 | 0.0003 |
|  | Lime\*fertiliser | 0.2157 | 0.827 | 0.5608 | 0.3107 | 0.292 | 0.9266 | 0.1084 | 0.0434 | 0.1279 | 0.1616 | 0.0566 | 0.0074 | 0.0006 | 0.047 | 0.0003 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| lime | Grass only | 4.1a | 4a | 2.8a | 4.3a | 3.2a | 2.6a | 4.6a | 2.9a | 2.2a | 4.9a | 2.5a | 1.7a | 5.2a | 2.2b | 1.9a |
|  | Grass+ Acacia | 4.2a | 4.1a | 2.9a | 4.6a | 3.2a | 2.6a | 4.8a | 3.0a | 2.3a | 5a | 2.6a | 2.0a | 5.2a | 2.4ab | 1.6a |
| Non-lime | Grass only | 4.2a | 4a | 2.9a | 4.2a | 3.9a | 2.8a | 4.3a | 3.2a | 2.4a | 4.4b | 2.8a | 2.1a | 5a | 2.8a | 1.9a |
|  | Grass+ Acacia | 4.3a | 4.2a | 2.7a | 4.4a | 3.6a | 3a | 4.6a | 3.1a | 2.4a | 4.8ab | 2.8a | 2.1a | 5.2a | 2.9a | 1.9a |
|  | **Main effect (Prob>P)** | | | | | | | | | | | | | | | |
|  | Lime | 0.3709 | 0.7246 | 0.6858 | 0.2158 | 0.0182 | 0.2379 | 0.1714 | 0.1233 | 0.2889 | 0.0069 | 0.0727 | 0.3316 | 0.1094 | 0.0023 | 0.528 |
|  | Acacia | 0.1278 | 0.0258 | 0.7402 | 0.0797 | 0.4086 | 0.6921 | 0.1843 | 0.9225 | 1 | 0.048 | 1 | 0.535 | 0.0669 | 0.2155 | 0.3647 |
|  | Lime\*Acacia | 0.7752 | 1 | 0.3669 | 0.6389 | 0.3743 | 0.7019 | 0.4764 | 0.195 | 0.6825 | 0.0917 | 0.7077 | 0.4995 | 0.3976 | 0.6429 | 0.4578 |

Table S2. Response of soil organic carbon (SOC (%)) and cation exchange capacity (CEC (cmolcKg-1k) to the application of manure derived from grass diet only, Acacia angustissima supplement to grass basal feed and NPK fertilizer

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Baseline** | | **Season 1** | | **Season2** | | **Season3** | | **Season4** | |
| **Treatment** | | **OC** | **CEC** | **OC** | **CEC** | **OC** | **CEC** | **OC** | **CEC** | **OC** | **CEC** |
| Lime | Manure | 0.68a | 5.69a | 0.81a | 8.06a | 1.39a | 11.37a | 1.31a | 14.99a | 1.60a | 19.39a |
|  | NPK | 0.67a | 5.72a | 0.69a | 8.01a | 0.71a | 10.95ab | 0.85abc | 14.66ab | 0.96abc | 19.46a |
|  | Non-fertiliser | 0.73a | 5.72a | 0.57ab | 7.05ab | 0.44a | 8.2bc | 0.47bc | 10.93b | 0.47c | 12.4c |
| Non-lime | Manure | 0.62a | 5.69a | 0.71a | 7.11ab | 0.78a | 9.53ab | 1.02ab | 13.26ab | 1.33ab | 17.33ab |
|  | NPK | 0.73a | 6.05a | 0.65ab | 7.12ab | 0.31a | 9.22ab | 0.75bc | 13.06ab | 0.83bc | 16.39b |
|  | Non-fertiliser | 0.40a | 5.63a | 0.36b | 5.34b |  | 5.34c | 0.27c | 5.56c | 0.23c | 6.99d |
|  | **Main effect (prob>P)** | | | | | | | | | | |
|  | Lime | 0.152 | 0.5703 | 0.0309 | 0.0117 | 0.3796 | 0.0009 | 0.0868 | 0.0002 | 0.1038 | <.0001 |
|  | Fertiliser | 0.4182 | 0.4561 | 0.0002 | 0.0252 | 0.0373 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
|  | Lime\*fertiliser | 0.1471 | 0.5076 | 0.4795 | 0.71 | 0.4802 | 0.6961 | 0.7591 | 0.0569 | 0.8991 | 0.0445 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| lime | Grass only | 0.70a | 5.94a | 0.81a | 7.24b | 1.76a | 10.04b | 1.30a | 13.6ab | 1.56a | 18.33b |
|  | Grass+ Acacia | 0.67a | 5.45a | 0.77a | 9.46a | 1.02a | 12.7a | 1.32a | 16.38a | 1.63a | 20.46a |
| Non-lime | Grass only | 0.60a | 5.56a | 0.73a | 6.44b | 0.85a | 8.8b | 0.95b | 12.17b | 1.23b | 16.88b |
|  | Grass+ Acacia | 0.63a | 5.83a | 0.69a | 7.78ab | 0.81a | 10.27ab | 1.10ab | 14.36ab | 1.43ab | 17.79b |
|  | **Main effect (Prob>P)** | | | | | | | | | | |
|  | Lime | 0.4472 | 1 | 0.1624 | 0.0084 | 0.2394 | 0.0126 | 0.002 | 0.0233 | 0.0063 | 0.0009 |
|  | Acacia | 1 | 0.583 | 0.9685 | 0.0011 | 0.4028 | 0.0068 | 0.2225 | 0.0035 | 0.1106 | 0.0061 |
|  | Lime\*Acacia | 0.7004 | 0.0774 | 0.4993 | 0.2489 | 0.4435 | 0.3411 | 0.3724 | 0.6521 | 0.3994 | 0.1829 |

Table S3. Response of soil organic carbon total N (%) and available P (ppm) to the application of manure derived from grass diet only, Acacia angustissima supplement to grass basal feed and NPK fertilizer

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Baseline** | | **Season1** | | **Season2** | | **Season3** | | **Season4** | |
| **Treatment** | | **TN** | **Av.P** | **TN** | **Av.P** | **TN** | **Av.P** | **TN** | **Av.P** | **TN** | **Av.P** |
| Lime | Manure | 0.07a | 4.62a | 0.08b | 4.46ab | 0.14a | 6.25a | 0.19a | 8.03b | 0.20ab | 8.74bc |
|  | NPK | 0.07a | 5.31a | 0.09a | 6.30a | 0.15a | 6.43a | 0.19a | 11.8a | 0.25a | 12.14a |
|  | Non-fertiliser | 0.06a | 4.77a | 0.06c | 4.08bc | 0.07bc | 4.87ab | 0.07b | 5.0c | 0.07c | 4.74d |
| Non-lime | Manure | 0.06a | 4.63a | 0.07bc | 4.08bc | 0.12a | 5.54a | 0.17a | 6.63bc | 0.18b | 8.13c |
|  | NPK | 0.06a | 5.72a | 0.08ab | 4.98ab | 0.12ab | 5.87a | 0.18a | 10.4a | 0.22ab | 10.64ab |
|  | Non-fertiliser | 0.05a | 4.85a | 0.03d | 2.96c | 0.04c | 2.81b | 0.04b | 2.78d | 0.04c | 2.77d |
|  | **Main effect (prob>P)** | | | | | | | | | | |
|  | Lime | 0.3249 | 0.7302 | 0.0002 | 0.0013 | 0.0046 | 0.0135 | 0.0165 | 0.0002 | 0.0235 | 0.0035 |
|  | Fertiliser | 0.2467 | 0.2995 | <.0001 | <.0001 | <.0001 | 0.0004 | <.0001 | <.0001 | <.0001 | <.0001 |
|  | Lime\*fertiliser | 0.9372 | 0.9367 | 0.2007 | 0.2358 | 0.3564 | 0.3163 | 0.7431 | 0.6129 | 0.9879 | 0.3486 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| lime | Grass only | 0.07a | 4.54a | 0.08a | 4.23a | 0.14a | 5.40b | 0.17ab | 7.55ab | 0.19ab | 8.27a |
|  | Grass+ Acacia | 0.06a | 4.69a | 0.07a | 4.633a | 0.13a | 7.10a | 0.20a | 8.52a | 0.22ab | 9.20a |
| Non-lime | Grass only | 0.06a | 5.07a | 0.06a | 4.19a | 0.13a | 5.42ab | 0.16b | 6.20b | 0.17b | 7.80a |
|  | Grass+ Acacia | 0.06a | 4.69a | 0.07a | 3.98a | 0.12a | 5.66b | 0.17ab | 7.06b | 0.19ab | 8.46a |
|  | **Main effect (Prob>P)** | | | | | | | | | | |
|  | Lime | 0.7067 | 0.9815 | 0.1951 | 0.1967 | 0.3943 | 0.0645 | 0.0201 | 0.0136 | 0.0176 | 0.2749 |
|  | Acacia | 0.5997 | 0.4987 | 0.6907 | 0.2584 | 0.5889 | 0.0182 | 0.0152 | 0.0782 | 0.026 | 0.1623 |
|  | Lime\*Acacia | 0.5794 | 0.3411 | 0.3553 | 0.7115 | 0.7675 | 0.0594 | 0.3067 | 0.9077 | 0.2768 | 0.7979 |

Table S4. Response of soil Ca2+ (cmolckg-1), Mg2+ (cmolckg-1) and K+ (cmolc kg-1) to the application of manure derived from grass diet only, Acacia angustissima supplement to grass basal feed and NPK fertilizer

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Baseline** | |  | **Season1** | |  | **Season2** | |  | **Season3** | |  | **Season 4** | |  |
| **Treatment** | | **Ca2+** | **Mg2+** | **K+** | **Ca2+** | **Mg2+** | **K+** | **Ca2+** | **Mg2+** | **K+** | **Ca2+** | **Mg2+** | **K+** | **Ca2+** | **Mg2+** | **K+** |
| Lime | Manure | 0.49ab | 0.21a | 0.33a | 1.43a | 0.82a | 0.47a | 2.74a | 1.38a | 0.51a | 4.27a | 1.82a | 0.57ab | 6.30a | 2.31a | 0.69a |
|  | NPK | 0.48ab | 0.13a | 0.22a | 1.2ab | 0.83a | 0.37a | 2.58a | 1.51a | 0.55a | 4.15a | 1.96a | 0.69ab | 5.95ab | 2.51a | 1.06a |
|  | Non-fertiliser | 0.52ab | 0.15a | 0.30a | 1.25ab | 0.62ab | 0.30a | 2.95a | 1.42a | 0.21a | 4.17a | 1.88a | 0.16ab | 6.37a | 2.42a | 0.20a |
| Non-lime | Manure | 0.48ab | 0.14a | 0.32a | 1.09ab | 0.77ab | 0.45a | 2.01ab | 1.22a | 0.57a | 3.39a | 1.68a | 0.70a | 4.49bc | 2.26a | 0.83a |
|  | NPK | 0.66a | 0.16a | 0.31a | 0.9bc | 0.30b | 0.43a | 1.66ab | 0.55b | 0.39a | 2.77ab | 0.55b | 0.39ab | 3.53cd | 0.68b | 0.47a |
|  | Non-fertiliser | 0.24b | 0.14a | 0.36a | 0.39c | 0.35b | 0.32a | 0.72b | 0.54b | 0.25a | 0.99b | 0.69b | 0.13b | 1.34d | 0.79b | 0.16a |
|  | **Main effect (prob>P)** | | | | | | | | | | | | | | | |
|  | Fertilser | 0.5918 | 0.7468 | 0.1913 | <.0001 | 0.0003 | 0.6908 | <.0001 | <.0001 | 0.8852 | <.0001 | <.0001 | 0.6468 | <.0001 | <.0001 | 0.3465 |
|  | Lime | 0.1501 | 0.6804 | 0.297 | 0.0008 | 0.0008 | 0.0614 | 0.2231 | 0.0002 | 0.0067 | 0.0095 | <.0001 | 0.0025 | 0.0105 | 0.0001 | 0.0147 |
|  | Lime\*fertiliser | 0.0754 | 0.5572 | 0.4293 | 0.0219 | 0.0173 | 0.8031 | 0.0604 | <.0001 | 0.4616 | 0.0167 | <.0001 | 0.2498 | 0.0071 | <.0001 | 0.1843 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| lime | Grass only | 0.48a | 0.15a | 0.35a | 1.32a | 0.65b | 0.41a | 2.50a | 1.30a | 0.40a | 3.85a | 1.66b | 0.44a | 5.57ab | 2.0a | 0.48a |
|  | Grass+ Acacia | 0.5a | 0.27a | 0.31a | 1.37a | 0.97a | 0.55a | 2.97a | 1.47a | 0.62a | 4.70a | 2.02a | 0.70a | 7.02a | 2.61a | 0.89a |
| Non-lime | Grass only | 0.50a | 0.16a | 0.29a | 1.12a | 0.80ab | 0.46a | 2.01a | 1.18a | 0.57a | 3.57a | 1.66b | 0.66a | 4.09b | 2.27a | 0.84a |
|  | Grass+ Acacia | 0.45a | 0.13a | 0.35a | 1.05a | 0.75ab | 0.43a | 2.01a | 1.26a | 0.60a | 3.21a | 1.70ab | 0.74a | 4.88b | 2.26a | 0.82a |
|  | **Main effect (Prob>P)** | | | | | | | | | | | | | | | |
|  | Lime | 0.8688 | 0.3796 | 0.78 | 0.0197 | 0.5372 | 0.6104 | 0.0493 | 0.1073 | 0.4319 | 0.051 | 0.0804 | 0.4229 | 0.0005 | 0.8356 | 0.4435 |
|  | Acacia | 0.8391 | 0.5517 | 0.7119 | 0.9131 | 0.0517 | 0.3955 | 0.4816 | 0.2091 | 0.2129 | 0.5426 | 0.0135 | 0.2854 | 0.0094 | 0.1699 | 0.3067 |
|  | Lime\*Acacia | 0.7075 | 0.2821 | 0.1636 | 0.522 | 0.0108 | 0.1127 | 0.4739 | 0.6808 | 0.3333 | 0.1566 | 0.0395 | 0.5456 | 0.3503 | 0.1503 | 0.2723 |

Table S5. Response of grain yield (t ha-1) and stover yield (t ha-1) to the application of manure derived from grass diet only, Acacia angustissima supplement to grass basal feed and NPK fertilizer

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Season 2** | | **Season 3** | | **Season 4** | |
|  | **Treatments** | **Grain** | **Stover** | **Grain** | **Stover** | **Grain** | **Stover** |
| Lime | NPK | 2.21a | 3.57a | 2.72a | 2.76a | 7.58a | 9.88a |
|  | Manure | 1.04bc | 1.75b | 1.54b | 1.91b | 4.37bc | 5.01b |
|  | Non-fert | 0.47c | 1.01b | 0.80bc | 1.06c | 2.24cd | 3.40b |
| No lime | NPK | 1.91ab | 2.95a | 2.40a | 2.76a | 6.86ab | 7.96a |
|  | Manure | 0.89c | 1.39b | 1.24bc | 1.48bc | 3.78cd | 4.11b |
|  | Non-fert | 0.47c | 0.97b | 0.74c | 1.06c | 1.66d | 2.94b |
|  |  |  |  |  |  |  |  |
|  | **Main effect** | | | | | | |
|  | Fertilser | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
|  | Lime | 0.4214 | 0.092 | 0.161 | 0.3894 | 0.216 | 0.03 |
|  | Fertiliser\*Lime | 0.8303 | 0.5367 | 0.7525 | 0.3988 | 0.9925 | 0.49 |
|  |  |  |  |  |  |  |  |
| Lime | Grass only | 1.17 | 1.87 | 1.48 | 1.97 | 3.71b | 5.10 |
|  | Grass+Acacia | 0.92 | 1.64 | 1.59 | 1.84 | 5.03 | 4.93 |
| No lime | Grass only | 0.90 | 1.15 | 1.20 | 1.40 | 2.86 | 4.18 |
|  | Grass+Acacia | 0.88 | 1.62 | 1.28 | 1.57 | 4.70a | 4.04 |
|  |  |  |  |  |  |  |  |
|  | **Main effect** | | | | | | |
|  | Lime | 0.6009 | 0.1574 | 0.0304 | 0.0861 | 0.3138 | 0.3114 |
|  | Acacia | 0.6549 | 0.6313 | 0.4712 | 0.9335 | 0.0184 | 0.8591 |
|  | Lime\*Acacia | 0.6987 | 0.1787 | 0.8911 | 0.5033 | 0.6472 | 0.9856 |