**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**

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**Supplementary material:**

Number of pages: 6

Number of tables: 5

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 |