

Supplementary material S1. General characteristics of the ‘Palo a Pique’ long-term experiment.

Feature	Description
Winter crops	Oat (<i>Avena sativa</i> L.), annual ryegrass (<i>Lolium multiflorum</i> L.), wheat (<i>Triticum aestivum</i> L.), and black oat (<i>Avena strigosa</i> Schreb)
Summer crops	Sorghum (<i>Sorghum bicolor</i> L.), foxtail millet (<i>Setaria italica</i> L.), soybean (<i>Glycine max</i> L.)
Pastures in short rotation	Red clover (<i>Trifolium pratense</i> L.), annual ryegrass, chicory (<i>Cichorium intybus</i> L.), Yorkshire fog (<i>Holcus lanatus</i> L.)
Pastures in long rotation	White clover (<i>Trifolium repens</i> L.), birdsfoot trefoil (<i>Lotus corniculatus</i> L.), tall fescue (<i>Festuca arundinacea</i> Schreb.), orchardgrass (<i>Dactylis glomerata</i> L.)
Permanent pasture	White clover, birdsfoot trefoil, annual ryegrass broadcast seeded and re-seeded every 5 years
Crop and pasture fertilization	Crops and pastures were fertilized with nitrogen (20-25 kg N/ha) and phosphorus (50-60 kg P ₂ O ₅ /ha) at seeding, forage crops were fertilized with urea during the grazing period (50 kg N/ha) and legume-based pasture fertilized every year with 40-60 kg P ₂ O ₅ /ha in fall. Since 2012 crops and pastures were fertilized with potassium (K) at seeding (15-25 kg K/ha per crop) because of declining soil K levels.
Grazing management	Direct grazing by British breed beef cattle (Hereford, Aberdeen Angus and Hereford – Angus cross). Forage crops and pastures were grazed rotationally by calves (160-180 kg liveweight, LW) and steers (300-400 kg LW) beginning in early fall (March-April) and for a 12-month period. During early spring and late summer, stocking rate was decreased due to the reduction in the grazing area associated with seeding of annual crop forages and first-year pastures. Approximately, each EU was grazed during one week between 8-10 times per year (17). Since 2019, unique livestock strategies were assigned to each pasture-crop rotation (see Supplementary File 3).

Supplementary material S2. Detailed description of the new livestock strategies for each pasture-crop rotation (2019-present)

Backgrounding of calves and finishing steers in long pasture-crop rotations in the long rotation (LR)

This system represents a standard for comparison. It is representative of one of the predominant livestock strategies in eastern Uruguay characterized by maintaining a high stocking rate during winter to maximize pasture utilization and animal performance during spring. Calves enter in fall (180 kg LW) and are kept in the system until they reach 490-520 kg LW. This process takes between 18 to 22 months. The critical season is winter because calves and steers coincide when pasture production decreases due to low air temperatures. For that reason, this system has the highest rate of on-pasture supplementation with high-moisture sorghum grain (HMSG, produced during the cropping phase of the LR) with or without protein concentrate (calves and steers, respectively). Because of the high requirements of grain supplementation, this system can 'buy' HMSG produced under similar protocols of production in other rotations (CC and/or SR) with a grain surplus.

Backgrounding of calves and finishing cows in short pasture-crop rotations in the short rotation (SR)

This system operates backgrounding and finishing of female categories. Female calves enter the system at 140-160 kg LW after weaning (6-8 months old) in fall. They are kept in the system for a year until they reach 330-350 kg LW when they are sold as replacement heifers. Three of the four paddocks of the rotation are sown each fall, thus, not being available for grazing. Therefore, the system supports only one animal category, preferably with light LW, at that time of the year. Female calves born late in the breeding season are the most suitable category for this system as they usually have lighter LW at weaning. Animal stocking rate is complemented with finishing cull cows in winter and summer when the annual forage crops are already established, increasing forage availability. Cows derive from the breeding herd from where they are to be culled because of age or reproductive failure. They enter the system at 400-450 kg LW in winter and summer and are kept for 100-120 days in each production cycle until they reach 480-520 kg LW, when they are sold to a slaughterhouse. This livestock strategy was chosen based on the complementation of pasture supply and animal demand by adjusting the time of entry of the different categories. It was also chosen for the ease of buying calves and cows in the region as well as selling replacement heifers, since the experiment is in an area with predominance of cow-calf operations.

Backgrounding of calves in crop-based rotations in continuous cropping (CC)

This system is specialized in backgrounding of calves. The calves are weaned and enter the system at 180 kg LW (6-8 months old) in fall. They are kept in the system for a year until they reach 360-380 kg LW when they are sold to finishers. This livestock strategy was chosen for its simplicity as this system is led by cropping systems and is not supposed to have too much infrastructure or time to devote to animals. Critical seasons are fall and spring when the grazing area in the rotation is significantly reduced due to sowing of forage annual crops. In those periods, animals are managed in the support area composed of natural grasslands and an improved pasture outside the rotation.

Finishing of steers in forage-based systems in permanent pastures (PP)

This system is specialized in finishing steers on a tall fescue-based pasture fertilized with high levels of urea (185 kg N/ha per year equally distributed in summer, fall, winter, and spring). Yearling steers enter in the system in late spring (260-280 kg LW) and are kept for 12 months until they reach 480-500 kg LW. This is the only system in which the animals enter in spring instead of in fall. This decision was made to have lighter animals and a lower stocking rate during summer when higher temperature, lower precipitation, and intensive grazing can compromise the growth and survival of tall fescue. This system was primarily chosen for the comparison with backgrounding of calves in crop-based systems (crop vs. forage; backgrounding vs. finishing).

Supplementary material S3. List of publications from the ‘Palo a Pique’ long-term experiment (1995-present)
(Sorted by year of publication)

BLANCO, F.; TERRA, J.; GARCÍA, F. Uso de elementos de la tecnología de siembra directa en producción forrajera en suelos de lomadas del Este. In: Jornada Anual de Producción Animal, 1996, Palo a Pique, Treinta y Tres, UY. [Resultados experimentales]. Treinta y Tres: INIA, 1996. p. 17-32. (Serie Actividades de Difusión, 110). INIA Treinta y Tres. Unidad Experimental Palo a Pique (UEPP).

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/4034/1/Ad-110-p.17-32.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F. (Ed.). Siembra directa y rotaciones forrajeras en las Lomadas del Este: síntesis 1995-2000 Montevideo (Uruguay): INIA, 2001. 100 p. (INIA Serie Técnica; 125)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/2869/1/111219240807141051.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F. Ciclo de cultivos de las rotaciones. In: TERRA, J.A.; GARCÍA PRÉCHAC, F. (Eds.). Siembra directa y rotaciones forrajeras en las Lomadas del Este: síntesis 1995-2000. Montevideo (Uruguay): INIA, 2001. p. 34-50. (INIA Serie técnica; 125)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/8589/1/ST-125-Terra-p.34-50.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F. Ciclo de pasturas de las rotaciones In: TERRA, J.A.; GARCÍA PRÉCHAC, F. (Eds.). Siembra directa y rotaciones forrajeras en las Lomadas del Este: síntesis 1995-2000. Montevideo (Uruguay): INIA, 2001. p. 51-78 (INIA Serie Técnica; 125)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/2869/1/111219240807141051.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F. Efecto de la intensidad de uso y laboreo sobre el recurso suelo y su calidad In: TERRA, J.A.; GARCÍA PRÉCHAC, F. (Eds.). Siembra directa y rotaciones forrajeras en las Lomadas del Este: síntesis 1995-2000. Montevideo (Uruguay): INIA, 2001. p. 8-33 (INIA Serie Técnica; 125)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/8587/1/ST-125-Terra-p.8-33.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F.; SCAGLIA, G.; ROVIRA, P.J. Producción intensiva de carne en rotaciones forrajeras con tecnología de siembra directa en lomadas del Este Treinta y Tres (Uruguay): INIA, 2003. p. 35-44 (INIA Serie Actividades de Difusión; 317) INIA Treinta y Tres

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/335/1/14445020908145851.pdf>

JORNADA ANUAL DE PRODUCCIÓN ANIMAL, 2003, PALO A PIQUE, TREINTA Y TRES, UY. Resultados experimentales. Treinta y Tres: INIA, 2003. 90 p. (INIA Serie Actividades de Difusión; 332). INIA Treinta y Tres. Unidad Experimental Palo a Pique (UEPP).

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/4120/1/Ad-332.pdf>

TERRA, J.A.; GARCÍA PRÉCHAC, F.; ROVIRA, P.J. Rotaciones forrajeras en siembra directa en lomadas del Este: evolución de indicadores 1995-2003 In: Jornada anual de producción animal, 2003 Resultados experimentales. Treinta y Tres (Uruguay): INIA, 2003. p. 83-89 (INIA Serie Actividades de Difusión; 332) INIA Treinta y Tres. Unidad Experimental Palo a Pique

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/349/1/14445280812100124.pdf>

TERRA, J.A.; MACEDO, R.; CORREA, J. Evaluación preliminar de materiales de sorgo azucarado bajo distintas alternativas de manejo de suelos en un argisol del Este. In: INIA TREINTA Y TRES. Cultivos de Verano UEPP. Resultados Experimentales 2005-2006. Treinta y Tres (Uruguay): INIA, 2006. p. 3-17 (INIA Serie Actividades de Difusión; 461)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9172/1/ad-461-Terra.pdf>

INIA TREINTA Y TRES. Cultivos de Verano. Unidad Experimental Palo a Pique. Treinta y Tres (Uruguay): INIA, 2006. 34 p. (INIA Serie Actividades de Difusión; 461) Trabajos que se realizan en el marco de las Rotaciones Agrícolas-Ganaderas de la UEPP lideradas por los Ing. Agr. PhD, José Terra y Álvaro Roel y el Ing. Agr. Ricardo Macedo.

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9171/1/ad-461.pdf>

TERRA, J.A.; ROEL, A. Impacto de la intensidad de uso del suelo y variabilidad espacial del terreno sobre la productividad de sorgo a escala de chacra en lomadas del Este. In: INIA TREINTA Y TRES. Cultivos de Verano UEPP. Resultados Experimentales 2005-2006. Treinta y Tres (Uruguay): INIA, 2006. p. 18-34 (INIA Serie Actividades de Difusión; 461)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9173/1/ad-461-Terra-1.pdf>

PRAVIA, V.; TERRA, J.A.; ROEL, A.; CORREA, J. Impacto de la intensidad de uso de suelo sobre la productividad del cultivo de sorgo en lomadas del este. In: INIA TREINTA Y TRES. Cultivos y forrajeras de verano. Resultados experimentales 2007-2008. Treinta y Tres (Uruguay): INIA, 2008. p. 7-22 (INIA Serie Actividades de Difusión; 538)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9188/1/ad-538-p.7-22-Pravia.pdf>

PRAVIA, V.; TERRA, J.A.; ROEL, A.; CORREA, J. Impacto de la intensidad de uso del suelo sobre los cultivos de sorgo y soja a escala de chacra en lomadas del este. In: INIA Treinta y Tres. Cultivos y forrajeras de verano. Unidad Experimental Palo a Pique. Resultados experimentales 2006-2007. Treinta y Tres (Uruguay): INIA, 2007. p. 8-28 (INIA Serie Actividades de Difusión; 499)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9168/1/Ad-499-p.8-28-PRAVIA.pdf>

INIA TREINTA Y TRES. Cultivos y forrajeras de verano. Unidad Experimental Palo a Pique. Resultados experimentales 2008-2009. Treinta y Tres (Uruguay): INIA, 2009. 30 p (INIA Serie Actividades de Difusión; 580) TÉCNICOS PARTICIPANTES: Ing. Agr., MSc, PhD Alvaro Roel (Programa Producción y Sustentabilidad Ambiental, Director Regional, INIA Treinta y Tres); Ing. Agr., PhD José Terra (Programa Producción y Sustentabilidad Ambiental).

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9195/1/ad-580.pdf>

TERRA, J.A.; CORREA, J. Productividad de sorgo granífero en función de la fertilización nitrogenada y el pastoreo del cultivo antecesor. In: INIA TREINTA Y TRES. Cultivos y forrajeras de verano. Unidad Experimental Palo a Pique. Resultados experimentales 2008-2009. Treinta y Tres (Uruguay): INIA, 2009. p. 19-29 (INIA Serie Actividades de Difusión; 580)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9194/1/ad-580-p.19-29-Terra.pdf>

TERRA, J.A.; PRAVIA, V.; SALVO, L.; CARBONE, A.M.; GARCÍA PRÉCHAC, F. Desde la viabilización de la siembra directa en suelos marginales hasta la oportunidad del manejo sitio específico de los mismos. In: [Actas]. Hoffman, E.; Ribeiro, A.; Ernst, O.; García, F. O., eds. Simposio Nacional de Agricultura de Secano, 1, 2009. Paysandú: Facultad de Agronomía, UDELAR, IPNI Cono Sur. p. 91-110.

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/5139/1/Simposio-Nacional-Agricultura-Secano-2009-p.91-110-Terra.pdf>

TERRA, J.A.; PRAVIA, V.; ROEL, A.; CORREA, J. Impacto de la intensidad de uso de suelo sobre la productividad del cultivo de soja en Lomadas del Este. In: INIA TREINTA Y TRES. Cultivos y forrajeras de verano. Unidad Experimental Palo a Pique. Resultados experimentales 2008-2009. Treinta y Tres (Uruguay): INIA, 2009. p. 1-18 (INIA Serie Actividades de Difusión; 580)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/9193/1/ad-580-p.1-18-Terra.pdf>

CANTOU, G.; TERRA, J.A. Evolución de las propiedades químicas del suelo en sistemas de agricultura forrajera (2006 - 2012). In: INIA Treinta y Tres. Jornada anual Unidad Experimental Palo a Pique 2012. Treinta y Tres (Uruguay): INIA, 2012. p.63-70 (INIA Serie Actividades de Difusión; 695)

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/10446/1/Ad-695-p.63-70.pdf>

ZERBINO, M.S. Efecto de rotaciones cultivos-pasturas en siembra directa y con pastoreo sobre las comunidades de Oligochaeta. (Crop-pasture Rotations in Effects No-tillage, with Grazing, on Oligochaeta Communities). Agrociencia Uruguay, v. 16, n. 1, p. 15-23, 2012.

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/11303/1/Agrociencia-uruguay.-2012.v.16.Zerbino.pdf>

DÍA DE CAMPO DE LA UNIDAD EXPERIMENTAL PALO A PIQUE, 2016, INIA TREINTA Y TRES, URUGUAY. Día de Campo de la Unidad Experimental Palo a Pique. Discutiendo los sistemas criadores. mano a mano" Treinta y Tres (Uruguay): INIA, 2016. Colaboración de: INSTITUTO PLAN AGROPECUARIO Y FUCREA.

URL: <http://www.ainfo.inia.uy/digital/bitstream/item/6461/1/2016-DC-UEPP-octubre-2016.pdf>

Supplementary material S4. Evolution of the basic set of metrics collected in the ‘Palo a Pique’ long term experiment (1995-2019). Superscript numbers mean measurement frequency: ¹Once per year; ²Once per season, ³Once per month or less, ⁴Once per month, except carcass data (every time animals are sent to slaughter).

Phases			
Matrix	I	II	III and IV
Soil¹	pH; Organic Carbon (g/kg); Nitrogen (%); Phosphorus (µg P/g); Potassium (meq/100g)	Continue with metrics from Phase I. <u>Add</u> : Na, Ca, Mg (meq/100g); Titable Acidity (meq/100g); Cation Exchange Capacity (meq/100g); Total Bases (meq/100g); Base Saturation (%); Potentially Mineralized Nitrogen (mg/Kg N-NH ₄)	<i>Continued</i>
Crops²	Yield (kg/ha)	<i>Continued</i>	<i>Continued</i>
Pasture³	Forage allowance pre-grazing and post-grazing (kg DM/ha); Sward height (cm); Pasture utilization (%), Nutritive Value (%)	<i>Discontinued</i>	Resume metrics from Phase I. <u>Add</u> : Forage stock (kg DM/ha/month); Daily growth (kg DM/ha/day); Botanical composition (%)
Supplements¹		Supply of concentrates, hay, and high moisture sorghum grain (kg/ha); Nutritive Value	<i>Continued</i>
Animals⁴	Stocking rate (kg LW/ha); LW gain (kg/a); Average daily gain (g/a/d); LW production (kg/ha/year)	<i>Partially discontinued</i>	Resume metrics from Phase I. <u>Add</u> : Anthelmintic (N° of treatments); Carcass yield (%); Hot Carcass Weight (kg); Carcass fat score and conformation
System¹	Inputs (U\$/ha); Outputs (U\$/ha); Gross margin (U\$/ha)	<i>Discontinued</i>	Resume metrics from Phase I. <u>Add</u> : Capital investment (U\$/ha); Nutrient balance (NPK); Life Cycle Assessment (CO ₂ -eq)