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Tese

Sistematização com declividade variada como ferramenta para diversificação de sistemas produtivos em terras baixas

Marcos Valle Bueno

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Marcos Valle Bueno

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"The mind that opens to a new idea, never comes back to its original size"

Albert Einstein

RESUMO

BUENO, Marcos Valle. **Sistematização com declividade variada como ferramenta para diversificação de sistemas produtivos em terras baixas** 2022. 99f. Tese de doutorado - Programa de Pós-Graduação em Recursos hídricos. Universidade Federal de Pelotas, Pelotas.

Em uma área experimental pertencente ao Instituto Nacional de Pesquisa Agropecuária (INIA-Uruguai) foi realizado a implantação de lavouras de arroz e soja em área com e sem sistematização com declividade variada visando irrigação (DVI). Para medir o efeito da DVI na produtividade de arroz foi feito um estudo comparativo das safras de arroz de dois anos 2018-2019 e 2019-2020 em um campo comercial (12 há) no Uruguai. Esta foi a primeira vez que o DVI foi implementado neste país. Para alcançar a alternativa DVI foi determinado um movimento de solo de 104 m3 ha^{-1}. A profundidade de corte foi em média de 0,03 metros, com corte máximo de 0,16 metros. O comprimento total e o número de taipas de arroz foram reduzidos em 14% e 28%, respectivamente, em comparação com o campo Controle adjacente que não foi realizado o DVI. Nesta mesma área foi avaliado o efeito do DVI em algumas propriedades físicas e químicas do solo. Os resultados mostraram que os valores médios de argila, Corg, PH, Ca, Mg e P aumentaram e silte, areia, K, *Na* diminuíram após DVI. A principal propriedade do solo afetada pelo corte e aterro foi a matéria orgânica. A produtividade apresentou uma redução significativa nas zonas de corte, mas com um aumento nas zonas de aterro. Em geral o sistema DVI não apresentou grandes alterações nas propriedades do solo. Para medir o efeito da DVI na produtividade de soja foi comparado os rendimentos de soja entre um campo classificado com precisão DVI e o de um campo tradicional (controle). Para isso, foi feito um estudo comparativo das safras de soja 2018-2019 e 2019-2020 em um campo comercial (10 há) no Uruguai. Para alcançar a alternativa DVI com irrigação por camalhões foi determinado um movimento de solo de 108 m3 ha^{-1}. A profundidade de corte foi em média de 0,02 metros, com corte máximo de 0,08 metros. A variabilidade da produtividade foi verificada a partir da condutividade elétrica aparente do solo em 0,30 m (ECa30), isso porque o Eca30 teve uma correlação positiva muito forte com o teor de sódio do solo (*Na*), que é um elemento que reduz a produtividade da cultura. Para ambos os anos do estudo, houve diferenças ($P<0,05$) nos rendimentos médios de grãos em campo entre os tratamentos DVI e Controle, embora os aumentos de rendimento e os decréscimos de rendimento estivessem frequentemente associados a zonas de alta ECa30. O Sistema DVI em zona com baixa concentração de *Na* apresentou até 35% a mais que o tratamento Controle.

Palavras-chave: Várzea. Suavização. Arroz. Soja. Irrigação. Manejo de água.

ABSTRACT

BUENO, Marcos Valle. **Land forming as a tool for diversifying production systems in lowlands.** 2022. 99p. Dissertation (Doctor of Engineering) - Graduate Program in Water resourses, Federal University of Pelotas, Pelotas.

In an experimental area belonging to the National Institute of Agricultural Research (INIA-Uruguay), rice and soybean crops were implanted in an area with and without land leveling with varying slopes for irrigation (LFI). To measure the effect of DVI on rice yield, a comparative study of the 2018-2019 and 2019-2020 two-year rice crops was carried out in a semi-commercial field (12 ha) in Uruguay. This was the first time that LFI was implemented in this country. To achieve the LFI alternative, a soil movement of 104 m3 ha-1 was determined. The cutting depth averaged 0.03 meters, with a maximum cut of 0.16 meters. The total length and number of rice levees were reduced by 14% and 28%, respectively, compared to the adjacent Control field in which the LFI was not performed. In this same area, the effect of LFI on some physical and chemical properties of the soil was evaluated. The results showed that the mean values of clay, Corg, PH, Ca, Mg and P increased and silt, sand, K, Na decreased after DVI. The main soil property affected by cutting and filling was organic matter. Productivity showed a significant reduction in cut zones, but with an increase in fill zones. In general, the LFI system did not show major changes in soil properties. To measure the effect of LFI on soybean yield, soybean yields were compared between a field accurately classified LFI and that of a traditional field (control). For this, a comparative study of the 2018-2019 and 2019-2020 soybean crops was carried out in a semi-commercial field (10 ha) in Uruguay. To achieve the LFI alternative with ridge irrigation, a soil movement of 108 m3 ha-1 was determined. The cutting depth averaged 0.02 meters, with a maximum cut of 0.08 meters. The productivity variability was verified from the apparent electrical conductivity of the soil at 0.30 m (ECa30), this is because the Eca30 had a very strong positive correlation with the soil sodium content (Na), which is an element that reduces the productivity of culture. For both years of the study, there were differences ($P<0.05$) in mean field grain yields between the DVI and Control treatments, although yield increases and yield decreases were often associated with zones of high ECa30. The LFI System in a zone with low *Na* concentration showed up to 35% more than the Control treatment.

Keywords: Wetlands. Land leveling. Rice. Soybean. Irrigation. Water management.

Lista de Figuras

Lista de Tabelas

Sumário

1 Introdução

As terras baixas da bacia hidrográfica da Lagoa Mirim, tanto do lado brasileiro como do lado uruguaio caracterizam-se por apresentam relevo em sua grande maioria plano com baixa declividade e com rugosidade a nível de micro relevo, onde predominam solos com baixa condutividade hidráulica, apresentando como principal característica a deficiência de drenagem. Os tipos de solo mais comumente encontrados são os Planossolos e os Gleissolos, também conhecidos como solos hidromórficos.

Esses solos além de possuírem uma pequena capacidade de armazenamento de água disponível, passam de úmido para seco de maneira muito rápida e vice-versa, isto torna este ambiente muito desafiador para as culturas de sequeiro, pois em períodos de estiagem a disponibilidade hídrica é muito reduzida.

Sendo assim este ambiente propiciou como atividade agrícola o cultivo de arroz irrigado (*oryza sativa*), e em alguns casos em rotação com pastagem, porém nos últimos anos vem sendo introduzida a soja (*glycine max*) e em uma escala menor o milho (*zea mayz*), como uma alternativa para a rotação de culturas, geração de renda e uma maneira de intensificação das culturas agrícolas neste sistema produtivo.

Desta forma a prática da intensificação sustentável (i.e., rotação de culturas, diversificação) se apresenta como uma forma do produtor obter mais sustentabilidade do seu sistema produtivo ao longo do tempo. Pesquisas tem mostrado que a inserção de novas culturas neste ambiente produtivo é uma alternativa viável para o produtor, porém ainda existem desafios a serem superados. A rotação com a soja apresenta benefícios como a redução de plantas daninhas, aumento da fertilidade do solo entre outros.

Para conseguir atingir altos níveis produtivos desta prática a nível comercial é necessário que o manejo da água seja feito de maneira correta e precisa, principalmente na drenagem que se constituem no principal problema, entretanto a irrigação também pode ser um fator importante para potencializar a produtividade das áreas.

Uma alternativa para atingir altos níveis produtivos é a utilização do sistema sulco – camalhão, que permite a irrigação e também promove uma melhor drenagem das áreas. Mas para que este sistema possa atingir seu máximo desempenho, é recomendado realizar ajustes na superfície do solo, pois como foi pontuado, no ambiente de terras baixas em geral a superfície do terreno apresenta imperfeições a nível de micro relevo, o qual desfavorece o adequado manejo da água, desta forma alternativas que visam melhorar a superfície para se obter um melhor manejo são ações necessárias para a implantação de sistemas para a intensificação sustentável.

Nos últimos anos vem sendo introduzido o uso de geotecnologias, que utiliza receptores GNSS (Global Navigation Satellite System), com sistema de correção RTK (Real Time Knematic) como uma possibilidade de melhorar as condições de irrigação e drenagem, através do aumento da precisão das atividades como entaipamento e drenagem, e com a adequação da superfície do terreno através da sistematização, podendo ser em plano (i.e. land leveling, land grading) com ou sem declividade (cota zero) ou com declividade variada (i.e. land forming) no ajuste das imperfeições do solo promovendo melhores condições de manejo da água superficial.

Uma maneira para a adequação e melhoria da superfície do solo é através da sistematização, sendo que na sua versão mais atual é realizada com o uso de sistemas GNSS, a utilização de softwares SIG (Sistema de Informação Geográfica) de geoprocessamento, o uso de equipamentos que trabalham com sistemas de controle e automação de alto.

A sistematização com declividade variada, a qual só pode ser realizada com o sistema GNSS, requer um movimento de solo e uma profundidade de corte menor, portanto mais economicamente viável e menos prejudicial para o solo. Um modelo que melhora a irrigação da lavoura de arroz, e também permite a irrigação de culturas de sequeiro (i.e. soja, milho) por sulcos com alto desempenho, é o modelo de sistematização com declividade variada visando a irrigação (DVI).

A sistematização favorece o aumento do potencial de diversificação do sistema produtivo com a possibilidade de irrigação de outras culturas, além do arroz, usando métodos por superfície. A cultura do arroz será beneficiada também, devido à uniformidade espacial, a semeadura em época mais adequada e diminuição do consumo de água.

Sendo assim, a introdução de novas tecnologias no sistema de rotação arroz irrigado - soja em terras baixas afim de tornar o ambiente produtivo mais sustentável e buscar uma utilização racional dos recursos naturais merece especial atenção por parte dos pesquisadores da área. Desta forma, entende-se que a sistematização com declividade variada do solo pode ser uma alternativa importante para potencializar a diversificação do uso das terras baixas.

2 Referencial Teórico

2.1 Ambiente produtivo de terras baixas da lagoa Mirim

A bacia hidrográfica da Lagoa Mirim (Figura 1) está localizada na porção meridional do estado do Rio Grande do Sul e na parte leste do Uruguai. Esta se assenta, sobre a planície costeira, e possui uma largura média de 20 km, e 3.750 Km² de área superfície, sendo 2.750 Km² em território brasileiro e 1.000 Km² em território uruguaio (ALM, 2008). No regime dominante, suas águas afluem através do canal São Gonçalo, à Lagoa dos Patos, para posteriormente serem lançadas no Oceano Atlântico, pelo canal de Rio Grande (KOTZIAN; MARQUES, 2004). Saraiva (2005) caracteriza o setor uruguaio da bacia, dividindo o território em função do relevo: (i) zona das serras; (ii) Zona das lombadas; e (iii) terras baixas. Nesta bacia foram identificadas 43 classes de solos na área, entre estes estão os planossolos e gleissolos, localizadas principalmente nas terras baixas.

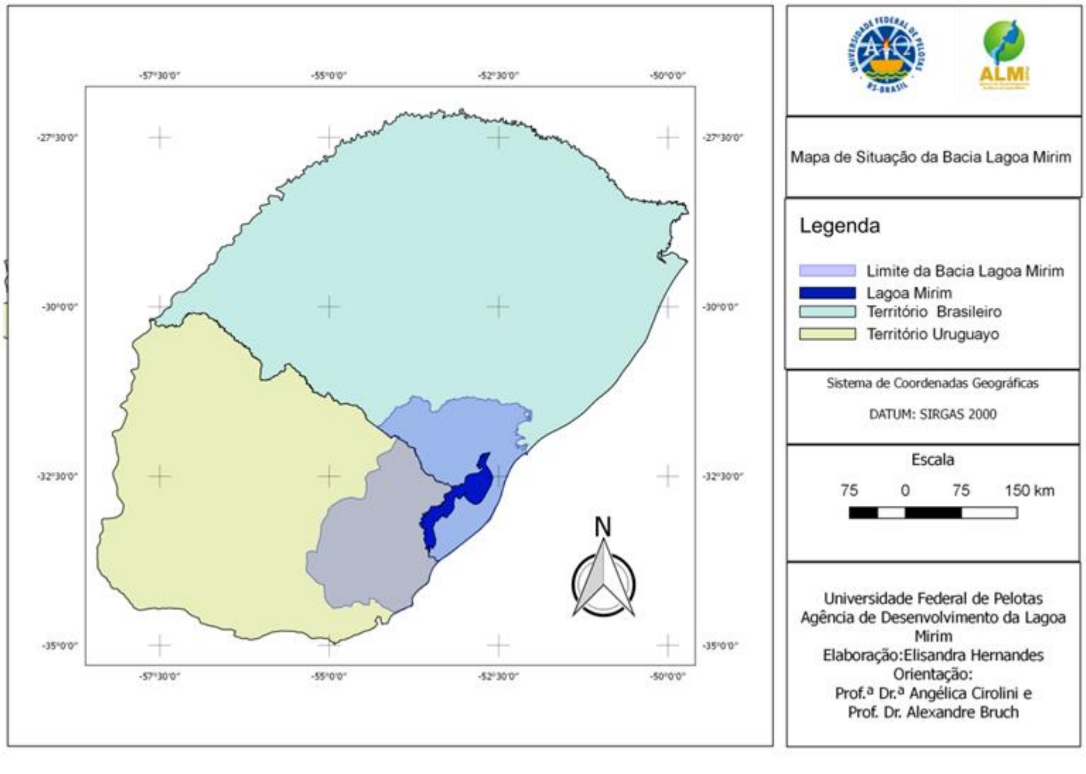


Figura 1: Mapa de localização da Bacia Hidrográfica da Lagoa Mirim (ALM, 2008).

Essas terras baixas apresentam predominantemente Planossolos e gleissolos, e a associação entre eles; caracterizam-se por serem solos hidromórficos com pobre drenagem natural, devido às terras baixas planas, perfis do solo com camada superficial rasa e camada subsuperficial quase impermeável (THOMAS; LANGE, 2014). Os solos de terras baixas apresentam baixa capacidade de armazenamento de água, limitando a disponibilidade de água para as culturas de sequeiro (STRECK et al., 2008).

Estas áreas, são propícias para o cultivo do arroz irrigado, caracterizam-se pela topografia plana e de difícil drenagem, onde os solos permanecem saturados nos períodos de maior precipitação pluvial. Estas características, normalmente são desfavoráveis para outras culturas (PARFITT et al., 2017). A principal cultura cultivada nesse ambiente é o arroz irrigado por inundação contínua. O restante da área é utilizado para o cultivo com pastagens (WINKLER, 2018).

Embora o arroz irrigado seja a principal atividade agrícola explorada em áreas de terras baixas, o cultivo da soja tem experimentado crescimento expressivo em áreas de rotação com o cereal nos últimos anos (MARCHESAN, 2016).

Macedo et al. 2021 mostrou que a maior produção de energia ocorre em sistemas de arroz mais intensos, que utilizam insumos que demandam maiores níveis energéticos. Existem alternativas de intensificação para sistemas de cultivo de arroz, que melhoram a eficiência energética em comparação com as rotações de pastagem de arroz de longo prazo.

A rotação do arroz com a soja melhorou o retorno energético do investimento em comparação com a rotação do arroz com pastagens de longa duração. Além disso, as lavouras de arroz que alternavam com soja ou pastagem exigiram menos investimento em energia e alcançaram melhor eficiência no uso de energia do que a monocultura de arroz (MACEDO et al., 2021).

A possibilidade de rotação de culturas com a soja amplia o uso das áreas, predominantemente utilizadas apenas com arroz, podendo se refletir positivamente na produtividade do arroz. A possibilidade de irrigação da soja é outra facilidade encontrada pela disponibilidade de água e a infraestrutura já estar organizada para o arroz.

A expansão no cultivo de soja em terras baixas deve-se ao aumento do potencial produtivo da cultura e, particularmente, ao cenário favorável de valorização da oleaginosa no mercado internacional.

O cultivo de soja em rotação ao arroz irrigado em terras baixas vai além dos benefícios econômicos, destacando- se a melhoria no controle de plantas daninhas, como o arroz-vermelho, pela utilização de herbicidas não seletivos, como o glifosato, a interrupção no ciclo de pragas e doenças, a possibilidade de implantação do arroz em sistema plantio direto e a incorporação de nitrogênio (N) ao sistema, pela fixação biológica de N (CASSOL, 2017). No entanto, o alagamento do solo afeta significativamente a fixação biológica de nitrogênio (YUN et al., 2008).

Da mesma forma, a cultura do milho apresenta potencial considerável de inserção nesse sistema de produção, dado ao alto potencial de produtividade, sob manejo adequado, representando, pois, uma possibilidade de redução na dependência de importação do cereal no Rio Grande do Sul (PARFITT et al., 2014).

Para a producao das culturas de sequeiro os solos de terras baixas apresentam naturalmente uma série de restrições físicas e químicas que podem limitar o desempenho agronômico e o potencial produtivo, dentre os principais tipos de estresse esta o hidrico.

Ainda que os solos hidromórficos, em função das suas características, possuírem grande aptidão ao cultivo de arroz irrigado por inundação, quando são implantadas outras culturas que compõem o sistema de produção, os resultados obtidos não são tão favoráveis principalmente em função da má drenagem (WINKLER, 2018).

A drenagem é o processo de remoção do excesso de água da superfície do solo, a drenagem superficial, que é a remoção do excesso de água da superfície do solo, para torná-lo adequado ao aproveitamento agrícola. É através da melhoria da drenagem superficial que se podem dar melhores condições aos cultivos agrícolas neste ecossistema (SILVA; PARFITT, 2004).

Esta drenagem é realizada com pequenos drenos, executada normalmente com valetadeira ou sulcador tipo pé de pato, após da semeadura da soja, ou antes, da semeadura do arroz de forma a garanti-lhe a boas condições de drenagem na época da semeadura (WINKLER et al., 2013). A melhoria da drenagem possibilita a semeadura do arroz em época mais adequada e beneficia a cultura da soja, que é sensível ao encharcamento (FRANTZ et al., 2015).

O déficit hídrico também é um dos fatores ambientais mais limitantes para rotação de culturas em áreas cultivadas com arroz irrigado. Além disso, a redução do conteúdo de água no solo pode potencializar alguns problemas relacionados ao solo. Dentre eles, a resistência do solo à penetração, que pode restringir o desenvolvimento radicular quando em níveis elevados (GIACOMELI, 2019).

É muito importante a adequação das áreas de terras baixas para o cultivo de sequeiro juntamente com a adoção de práticas de manejo que possibilitem a diminuicao de estresses, são medidas de extrema importância para garantir a estabilidade produtiva da cultura nesse ambiente. As alternativas de manejo que podem ser exploradas para atingir esse objetivo são a sistematizacão do solo e o cultivo em sulco-camalhões para adoção da irrigação.

2.2 Sistematizacão do solo

A sistematização dos solos (Figura 2) de terras baixas vem sendo utilizada há mais de meio século, em função de seus vários benefícios, principalmente o de uniformizar a distribuição da água de irrigação (WHITNEY et al., 1950; BRYE et al., 2003). Consiste no processo de adequação da superfície natural do terreno de forma a transformá-lo num plano ou numa superfície curva organizada, visando melhorar o manejo da água em solos de terras baixas com micro relevo irregular (PARFITT et al., 2004a; WALKER, 1989).

De acordo com Righes (2006), a sistematização em solo de várzea aumenta a eficiência de controle da água de irrigação e na operação das máquinas agrícolas, tanto no processo de semeadura como na colheita, além de permitir a redução da altura da lâmina de água sobre o solo, reduzindo o uso de água, torna a distribuição de agua mais uniforme melhorando a lucratividade (Jat et al., 2009).

Durante esta prática, ocorrem significativos movimentos de solo com cortes nas partes relativamente altas e aterros nas partes relativamente baixas, acarretando alterações no ambiente onde a planta se desenvolve (i.e., há um efeito da sistematização sobre os atributos físicos, químicos do solo e biológicos) e consequentemente, sobre a variabilidade espacial destes atributos na área.

Em estudos realizados por Aquino et al. (2015), Brye et al. (2006), Parfitt et al. (2013; 2014) e Winkler (2018) os autores caracterizaram o impacto da sistematização sobre a magnitude, variabilidade e distribuição espacial dos atributos físicos e biológicos e avaliaram a relação entre esses atributos, utilizados para as culturas irrigadas de arroz e soja. Concluíram que a sistematização afetou significativamente a magnitude e a variabilidade espacial dos atributos físicos e biológicos, bem como as relações entre eles. Os resultados encontrados por esses autores fora utilizando o sistema de laser para realizar o trabalho de sistematização.

Segundo Parfitt et al. (2014) a relação observada entre os atributos químicos e a profundidade dos cortes e/ou aterros indica que o mapa de cortes e aterros, obtido no projeto de sistematização, é uma ferramenta útil para a recuperação do solo nas zonas degradadas através da adição de corretivos e/ou fertilizantes químicos ou orgânicos. Cabe ressaltar que os autores avaliaram esta relação três meses após a sistematização da área.

Figura 2: Operação de sistematização com declividade variada.

A sistematização desde 1970 é realizada com controle de Raios Laser que permite sistematizar em plano com ou sem declividade, portanto com declividade uniforme em toda a área. Nos últimos anos com o surgimento do sistema que utiliza receptores GNSS-RTK (Figura 3) é possível implantar no campo qualquer tipo de superfície, já que o controle passou a ser pontual (x, y, z) com precisão abaixo do centímetros (SANTOS et al., 2017). Este sistema (Figura 3) recebe sinais de correção de uma base RTK, e através de um projeto realizado com a ajuda de um software e inserido no monitor do trator, realiza os corte e aterros da área de forma automática (BUENO et al., 2020).

Para a sistematização do terreno por meio do sistema GNSS-RTK, o processo se inicia com o levantamento planialtimétrico da área, determinando-se a altura de uma malha de pontos no campo, comumente entre 200 a 400 pontos por hectare. Por meio de software específico, obtém-se o modelo digital de elevação (MDE) do terreno, e, de posse do MDE, é realizado o projeto de sistematização (BUENO et al., 2020).

A sistematização que resulta em múltiplas declividades dentro da mesma área é chamada de sistematização com declividade variada (Suavização). Isso pode resultar em uma menor agressão do solo e custos gerais mais baixos do que a sistematização com declividade uniforme (PARFITT et al., 2017). A sistematização com declividade variada é uma opção para melhorar a drenagem e o manejo de irrigação nos solos de várzea mal drenados (BUENO et al., 2020).

Figura 3: Componentes do sistema GNSS-RTK.

A sistematização com declividade variada visando irrigação – DVI elimina todas as depressões e também as elevações (denominadas coroas), permitindo a irrigação por sulco nas culturas como soja e milho.

Numa determinada área é possível realizar vários tipos de sistematização: plano sem declividade; plano com declividade; e segundo uma superfície curva com declividade variada. A escolha depende do tipo do relevo da área, bem como o sistema de produção planejado, ou seja, se quer rotação de culturas ou não. Ainda é possível sistematizar locais específicos da área se for conveniente (BUENO et al., 2017).

2.3 Sistema sulco – camalhão

O sistema sulco-camalhão (Figura 4) consiste na estruturação da lavoura para a irrigação por sulcos, por meio do cultivo sobre os camalhões formados entre os sulcos. O sistema é indicado para solos planos, com declividades uniformes, geralmente requerendo a sistematização do terreno. O comprimento e a largura do sulco-camalhão são determinados pelas circunstâncias naturais, isto é, a declividade do terreno, tipo do solo, taxa de infiltração e vazão de água disponível. Entretanto, outros fatores podem ter influência tais como a profundidade da lâmina de irrigação, o manejo da cultura e o comprimento do quadro da lavoura (SILVA et al., 2006).

Figura 4: Implantação e desenvolvimento da cultura no sistema sulco – camalhão da área em estudo.

As culturas de sequeiro em áreas de terras baixas apresentam muitas limitações, devido às características dos solos apresentarem condições de deficiência na drenagem, além do relevo plano com camada subsuperficial adensada e hidromórfica, provindo da iluviação de argila (PINTO; MIGUEL; PAULETTO, 2017; DENARDI, 2017), com isso a cultura da soja em condições de excesso hídrico ou escassez de água não expressa seu máximo potencial produtivo (BAJGAIN et al., 2015).

Deste modo, manejos para melhorar as condições do cultivo de culturas de sequeiro foram impulsionados em áreas de terras baixas, como o uso de sistema de sulco-camalhão para auxiliar na drenagem e irrigação, além de minimizar o estresse das plantas, uma vez que em períodos chuvosos, os sulcos contribuem para o escoamento da água, e em períodos de estiagem facilita a irrigação nas áreas (PARFITT et al., 2017). O objetivo dessa técnica é proporcionar melhores condições para o pleno desenvolvimento das culturas de sequeiro.

2.4 Ferramentas de Geotecnologias e agricultura de precisao

Agricultura de precisão (AP) é o termo usado para descrever o objetivo de aumentar a eficiência na gestão da agricultura. É uma tecnologia em desenvolvimento que modifica técnicas existentes e incorpora novas para produzir um novo conjunto de ferramenta. Afim de mostrar o melhor desempenho dos sistemas estudados foram utilizadas ferramentas de geotecnologias e agricultura de precisao para que em uma maior escala espacial se possa representar melhor a variabilidade da variavel em estudo (BLACKMORE, 2003).

2.4.1 Mapa de produtividade

O mapeamento da produtividade (Figura 5) e a amostragem do solo tendem a ser a primeira etapa na implementação da AP. Os mapas de rendimento são produzidos a partir do processamento de dados de uma colheitadeira adaptada que possui um sistema de posicionamento do veículo integrado a um sistema de registro de rendimento (MOLIN et al., 2015).

Figura 5: Utilização de sensores de colheita para a geração dos mapas de produtividade, os dados da colhedora foram pesados em um graneleiro com balança afim de aferir os dados.

O uso de mapas de produtividade para caracterizar a variabilidade das lavouras tem-se mostrado um importante parâmetro pois se trata da representação gráfica da resposta das plantas às condições de manejo e ambiente submetidas, sendo considerado o resultado que se obteve com as técnicas empregadas (MOORE, 1998).

A possibilidade de se coletar dados ininterruptamente, faz dos mapas de produtividade a informação mais completa da lavoura; por outro lado, a grande quantidade de dados coletados possibilita a ocorrência de erros. Deste modo, a utilização de um grande número de informações referentes ao solo ou à cultura, tem sido a forma usual para tentar explicar a variabilidade produtiva das lavouras (SANTI, 2007).

O método de comparação por faixas adjacentes é uma técnica simples e de baixo custo para avaliar comparações de tratamento em uma escala significativa para os produtores. Neste método, faixas paralelas e alternadas de dois tratamentos agronômicos são aplicadas a um campo inteiro. Este método pode ser usado para comparar cultivares, tratamentos de lavoura, seleções de pesticidas, aplicações de nutrientes ou qualquer par de tratamentos agronômicos (BLACKMORE, 2003).

2.4.2 Eletrocondutividade aparente do solo

A condutividade elétrica aparente do solo (ECa) originou-se na medida da salinidade do solo, problema muito pertinente em zonas áridas associadas com lavouras de agricultura irrigadas e com áreas com lençóis freáticos de baixa profundidade (CORWIN; LESCH, 2005).

Sabemos que a ECa do solo é muito influenciada por uma vasta combinação de propriedades físico-químicas do solo, tal como: sais solúveis; mineralogia e conteúdo de argila; quantidade de água presente no solo; densidade volumétrica; matéria orgânica e temperatura do solo (AMIN, 2004).

Figura 6: Equipamento Veris utilizado para medir a condutividade elétrica do solo

Esse sistema compreende uma estrutura metálica composta de seis discos de cortes, servindo como eletrôdos de medidas (Figura 6). Essa estrutura é engatada a um veículo de arraste (trator, caminhonetes, etc.) para a medida contínua de ECa, composto também por uma unidade eletrônica para coleta e armazenamento de dados de condutividade elétrica junto com uma entrada para sistema de georreferenciamento por satélite, GPS - Global Position System (KACHANOSKI et al., 1988).

O sistema em si é fechado e calibrado segundo o fabricante, não deixando o usuário fazer adaptações que permitam a sua utilização além daquela que foi projetado. O fato de o sistema usar seis eletrodos e usar o método de medida de quatro pontos se deve a fazer a medida em duas profundidades diferentes praticamente em tempo igual, ou seja, dois sistemas de quatros pontos em um só, utilizando a mesma fonte de corrente, para os dois sistemas. Esse sistema é produzido e fabricado pela empresa Veris Technolgy, Nebraska USA, ilustrado na Figura 6 (SALINA, KS, USA).

3 Objetivo

3.1 Objetivo geral

Com a técnica de sistematização com declividade variada visando irrigação (DVI) desenvolver uma intensificação sustentável no uso dos solos de terras baixas da bacia da Lagoa Mirim.

3.2. Objetivo específico

1 – Capítulo I

A) Avaliar as uniformidades de distribuição de lâmina de irrigação de arroz de um campo com DVI com o de um campo tradicionalmente nivelado (controle),

B) Determinar como as áreas cortadas e aterradas no campo DVI diferem em termos de rendimento de arroz.

C) Comparar através de três métodos de colheita (escala espacial) os impactos de rendimento do DVI.

2 – Capítulo II

A) Comparar os rendimentos de soja entre uma área sistematizada com declividade variada e irrigada por sulcos com um campo com sistema de produção tradicional (controle).

3 – Capítulo III

A) Avaliar os impactos do DVI por meio da avaliação das magnitudes, variâncias e distribuições espaciais de propriedades físicas e químicas selecionadas do solo de uma área de terras baixas no Uruguai; verificação da existência de relação entre a magnitude dos cortes e/ou aterros e as magnitudes das propriedades físicas do solo após o DVI.

4 Hipótese

Através da utilização da técnica de sistematização com declividade variada (Suavização) é possível melhorar o manejo de água nos solos das terras baixas da bacia da Lagoa Mirim, assegurando a diversificação e o rendimento do sistema produtivo pela inserção da soja, sem afetar as propriedades do solo e a produtividade do arroz.

5 Capitulo I - Land-forming for irrigation (LFI) on a lowland soil protects rice yields while improving irrigation distribution uniformity.

5.1 Introduction

Lowlands have limited roughness surface (KAMPHORST et al., 2000) and low field slopes (BORSELLI; TORRI, 2010; WINKLER et al., 2018b) and feature hydromorphic soils with low hydraulic conductivities. Dense, impervious B horizons make these soils well suited for irrigated rice production (LIMA et al., 2009).

For agricultural research increasing crop production to meet future food demand is a challenging task (HUNTER et al., 2017), the intensification of land use like rice-soybeans systems in Arkansas USA and Brazil (BRYANT et al., 2012; MARTINS et al., 2016) are examples that can lead to this increase. Macedo et al. (2021) showed that intensification alternatives exist for rice cropping systems like rice-soybean rotations that improve energy use efficiency and return on investment. However, soybeans are prone to losses owing to waterlogging (BORTOLUZZI et al., 2018; SARTORI et al., 2016) and drought stress (HEATHERLY; SPURLOCK, 1993). Thus, successful adoption of alternative agronomic crops into rice cultivated in lowland conditions requires that both drainage and irrigation issues be successfully addressed (BUENO et al., 2020).

One way to promote adoption of alternative crops is the use of raised seedbeds that improve drainage in lowland soils (GOLLO et al., 2020; CASSOL et al., 2020), and also improves the physical characteristics of the soil and allows the use of a furrow irrigation system (GIACOMELI et al., 2016; SARTORI et al., 2016). A practice that can enhance irrigation and drainage, improves water transport and distribution (MIAO et al., 2021; ENCISO et al., 2018), facilitating timeliness of rice planting (DA ROCHA et al., 2017). Raised seedbed can also promote the use of water-conserving irrigation management practices (CASSOL et al., 2020).

Land-leveling (LL) is used in agriculture to modify the soil surface to standardize its slope (BRYE et al., 2006), facilitate the distribution of water and improve field conditions for other agricultural practices, thus providing a uniform distribution and water savings (JAT et al., 2009; BAI et al., 2017). A uniform slope are created, enabling a continuous flow of water within the field (KHAN et al., 2007), improving irrigation and drainage, and the effectiveness of cultivation operations, controlling the waterlogging and erosion risks. Such an operation allows for better production in both dry and rainy, seasons (QUIROS et al., 2020). Other benefits of LL include reduction in weeding, labor, and energy costs (ARYAL et al., 2018; ABDULLAEV et al., 2007) and increasing yields (NARESH et al., 2014).

During LL, the topsoil of relative higher elevation zones are removed (cut) and deposited in relative lower elevation zones (fill), this operation could have negative impacts on soil conservation (AQUINO et al., 2015; BRYE et al., 2006). The depth magnitude of cut is important since the depth of the topsoil horizons will be exploited by the new crop roots, the cut areas may present negative agricultural effects (PARFITT et al., 2014; CAZANESCU et al., 2010). Jat et al. (2009) also detect that significant depths of topsoil are removed from some locations and deposited on others, thereby removing the primary source of nutrients for the crop, it may adversely affect soil fertility, at least in the early years after exposure to the low fertile soil layers, requiring additional soil amendments and fertilizers. The cut and fill areas can be identified and used to plan field operations (ALZOUBI et al., 2018). Although land leveling is an efficient way of increasing efficiency of the water source throughout the growing season, it is a rather expensive procedure, and, in some cases, a significant movement of earthwork may be required depending on the topography of the field (ENCISO et al., 2018).

Owing to these agronomic and economic issues, LL has not been widely adopted by farmers in South America (IRGA, 2018; MENDEZ, 2021). As a result, the vast majority of rice fields consist of lowland soils with native topography which typically includes numerous swales and complex flow paths that greatly complicate surface irrigation methods. To facilitate rice flooding, earthen levees (bunds) are constructed using 0.05-m contours. This traditional field leveling system results in many closely spaced levees that require considerable soil disturbance and result in less-than-optimal flood management (Figure 7).

Figure 7: Photograph of a closely-spaced levee leveling system traditionally used for rice production on lowland soils in Uruguay and Southern Brazil.

A technological advancement called Land Leveling with Variable Slopes, also known as land-forming, combines global navigation satellite systems (GNSS) using real-time kinematic (RTK) correction and specialized topographic software (BUENO et al., 2020). Plani-altimetric surveys that use RTK systems provide high accuracy, especially along the z-axis (i.e., height) (RABELO et al., 2019; GARRIDO et al., 2019). In contrast to traditional laser land-leveling that produces a two-dimensional design having a single field slope, GNSS and machine control systems allow grade control to be achieved in three-dimensions. Thus, when RTK and GNSS technologies are used in conjunction with specialized software, designs with multiple slope directions and magnitudes can be generated within one field design.

One such land-forming option is Land-forming for Irrigation (LFI). LFI consists of smoothing the soil surface with automated land leveling equipment. This equipment can execute the software prescription that indicates the areas of the field that need to be cut or filled. All depressions and high points of the field are eliminated, allowing more uniform flow of water. This alternative method, explained by Bueno et al. (2020), may require smaller amounts of soil to be moved and, consequently, shallower cutting depths, than laser-leveling while still improving irrigation and drainage compared to 2-D laser leveling. It may also reduce soil disturbance associated with traditional levee-based leveling systems used in rice growing regions of Uruguay and South America.

It is anticipated that precision grading will be increasingly adopted in Uruguay and South America. However, the availability of combine yield monitors (COOK; BRAMLEY, 1998; BULLOCK et al., 2019) necessary to assess the impacts of these practices on crop yields at field-scale is uncommon. As a result, the manual (i.e., hand) collection of harvest samples may be required but it is not clear that methods will be sufficient to capture the effects of grading at field scales.

The hypothesis of this study is that LFI will allow for improved irrigation distribution uniformity with little negative impacts on crop productivity relative to a traditional levee-leveling practice. The objectives of this study were to (1) compare rice yields irrigation distribution uniformities of a LFI precision-graded field to that of a traditionally-leveled field (control), (2) determine how cut and filled areas in the LFI field differ in terms of rice yield, and (3) compare three harvest methods in terms of ability to capture the yield impacts of land-forming at field scale.

5.2. Materials and methods

5.2.1. Experimental area

Field experiments were conducted during the 2019/20 and 2020/21 growing seasons in a 12-ha field located in Paso de la Laguna, Treinta y Tres department (Lat: −33.16S; Long: −54.10W) in eastern Uruguay (Figure 8). The field had been fallowed as grassland for eight years with rice being the last crop cultivated. The field was divided into two equal areas, one area where the land-forming for irrigation (LFI) project was performed and the other half where no alteration of the native topography occurred; the unaltered portion served as the study control (Figure 8). Mean annual rainfall at the site is 1360 ± 315 mm; annual total potential evapotranspiration is 1138 ± 177 mm; mean monthly temperature is 22.3 ± 0.9^{o}C (summer) and 11.5 ± 0.8^{o}C (winter). The solar radiation and precipitation data are in Appendix 1. The Planosol, having a mapping unit of “La Charqueada” (MGAP, 1976), is typical of the lowland areas of Uruguay where rice rooting depth is limited by the presence of a claypan at approximately 20- to 30-cm. The chemical and physical characterization of the soil is in Appendix 2.

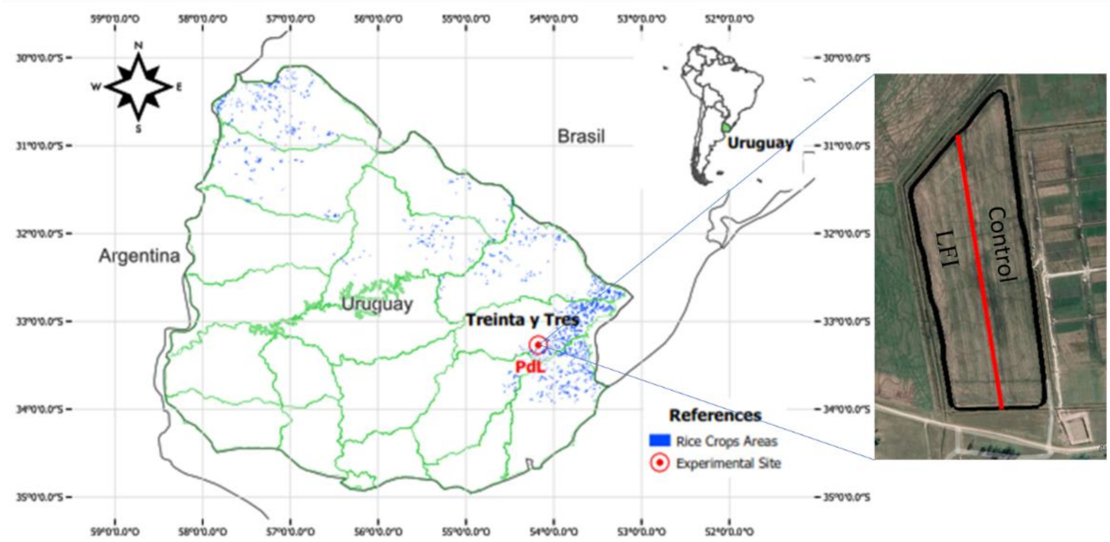


Figure 8: Rice cultivation regions in Uruguay. The inset shows the commercial-scale 12-ha field, located in Paso de la Laguna (PdL) of the Instituto Nacional de Investigación Agropecuaria (INIA), that was equally divided into the Land-Forming for Irrigation (LFI) field and non-graded field (Control) used in this study. (Uruguay map courtesy of Federico Campos).

5.2.2. Digital Elevation Model and Land-forming for Irrigation (LFI) Project Design

A planimetric survey of the 12-ha field was conducted using a tractor equipped with a monitor and GNSS receiver antenna with RTK base station using methods described by Aziz et al. (2009). The resulting elevation data were processed using WM-Form version 1.3 software (Trimble, Sunnyvale, CA 94085) to generate a digital elevation model (DEM) of the field surface.

Calculations for the LFI design were performed using WM-Form software using a cut-to-fill ratio of 1.2 (GAMERO; BENEZ, 1989). This design was generated in the sub-design area mode which allows the user to choose the direction and minimum magnitude of a preset slope. Both cut and fill volumes are balanced in a way that depends on factors such as soil compaction. These calculations were performed using 3-m grids, a balanced-soil movement criterion, and a minimum slope of 0.05% (BUENO et al., 2020).

5.2.3. LFI Project Implementation

During the spring of 2019 the LFI design was uploaded onto a computer control system of a tractor (New Holland, TM 7020) equipped an earth-moving scraper (Los Antonios, 4 m of width). The scraper was equipped with control module and valves to automatically remove (cut) and deposit (fill) soil as per the design.

5.2.4. Agronomics

On 11 November 2019 and 20 October 2020, the LFI and Control fields were planted with a long maturity *Indica* rice cultivar, INIA Olimar, using a Semeato model 249 grain drill (https://www.semeato.com.br/) and 17-cm row spacing. Both sowing dates fell within the window for optimal rice planting in Uruguay. Land preparation, weed control, all were performed on dry soil. Nitrogen fertilizer was applied pre-flood (dry soil) and at panicle initiation (flooded soil). Other key agronomic practices and dates are presented in Table 1.

Table 1: General management practices by season.

	Season	
	2019/2020	**2020/2021**
Sowing date (kg ha^{-1})	Nov 11 (140)	Oct 20 (140)
Phosphorous fertilization	Nov 19 (170)	Oct 16
Potassium fertilization (kg ha^{-1} K_2O)	Nov 19 (50)	Oct 16 (191)
Emergence date	Nov 22	Nov 4
Pre-flood nitrogen application (kg ha^{-1} N)	Dec 4 (50)	Nov 23 (200)
Flood initiation date	Dec 5	Nov 24
Mid-season nitrogen application (kg ha^{-1} N)	Jan 5 (60)	Dec 18 (40)
50% flowering date	Feb 9	Feb 1
Flood termination date	Mar 11	Mar 3
Harvest date	Mar 30	Mar 19

5.2.5. Irrigation Management

For each 6-ha field, earthen levees (bunds) were constructed on 0.05-m contours as is common in Uruguay and region. Irrigation water from a surface reservoir was supplied to each field via a secondary canal. Plastic irrigation tubing (10-mil (thickness) x 12-cm (diameter); Delta plastics) was used to distribute irrigation water from the canal to each paddy of each field (Figure 9). For each field, the irrigation poly-tubing was attached to a propeller flow meter (Mccrometer, Macmag3000 model) and the irrigation discharge rates set at approximately 2 liters per sec. Irrigation management was performed by INIA personnel.

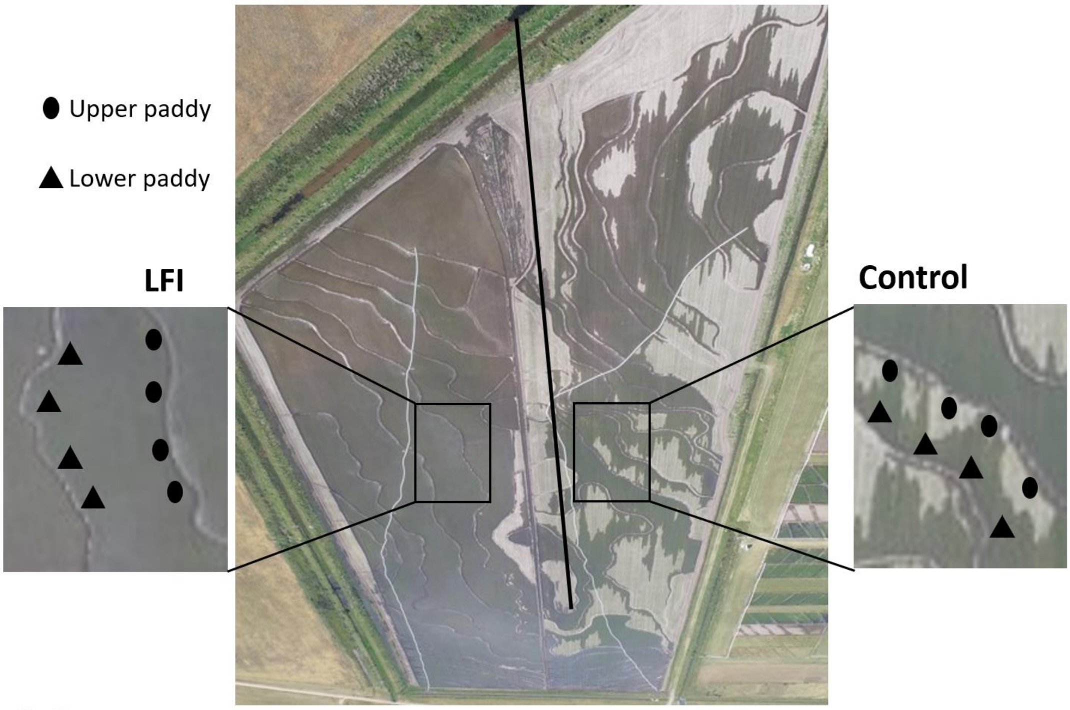


Figure 9: Aerial photograph showing visual differences in irrigation distribution uniformities in the 6-ha land-grading for irrigation (LFI) field (left) and 6-ha ungraded 6-ha Control field (right) that used a traditional rice levee leveling practice. The insets show how water depths were measured manually in the along the tops (●) and bottoms (▲) of five rice paddies of each field. Plastic poly-tubing (two white lines originating from the bottom of the photograph) was used to simultaneously distribute irrigation water from the canal to each paddy. (Photograph was taken on 25 Nov 2020).

5.2.6. Irrigation distribution uniformity measurements

A metal ruler was used to measure the uniformity of irrigation water depths on 02 and 17 December 2020. A total of 192 measurements (96 per treatment) were made. Of the 96 measurements, 48 were made along a transect that intersected the upper levees of five rice paddies and 48 measurements were made along a transect that intersected the lower levees of five paddies in each field. Figure 9 (insets) depict how these measurements were performed near the tops and bottoms of levees.

5.2.7 Collection and Comparisons of Rice Yields

Three methods used to harvest the rice fields each season: (A) two manually-harvested transects, (B) two field-length combine test strips, and (C) complete combine harvest of each field (Figure 10). The three resulting datasets were used to (a) compare average grain yields of the LFI and Control fields and

(b) determine relationships, if any, existing between yields and cut-and-fill depths in the LFI field. Each harvest method is described below.

Manually-harvested grain samples: In both study years, a quadrangle having an area of 1.8 m^2 and scythe were used to manually harvest rice samples along two transects each in the LFI (23 samples) and Control fields (25 samples), as shown in Figure 10A. The sample locations where georeferenced using a handheld GPS unit (Mobile Mapper 50, Spectra Precision). Grain moisture levels were determined prior to harvest to ensure that moisture was below 21% when these samples were collected. Afterward collection, the grain samples were manually threshed, weighed, and the grain yields normalized to 14% moisture.

Machine-harvested grain samples (combine test strips and complete field harvest): After the manually-harvested samples were collected, the fields were harvested using a combine harvester (New Holland, TC5070 model) equipped with an AgLeader yield monitor (model PF 3000; Ames, IA, USA), global positioning system (GPS), and a 5-m wide draper header. At the start of each harvest season, the yield monitor was calibrated as per Griffin et al. (2008) using a grain cart with certified scale. Yield data (yield, grain, moisture, longitude, and latitude) were downloaded and imported into Ag Leader Spatial Management System (SMS) software geographic information system to construct yield maps. The data were analyzed and processed using ArcGIS version 10.6 software (ESRI, Redlands, CA, USA). Outliers in the yield data were removed as per Vega et al. (2019).

The combine was used to harvest each field in two ways: First, two test strips, each 10- x 500-m (0.5-ha), were harvested in each field. Each strip was made by making two passes with the combine down the length of each field (Figure 10B). Secondly, the remainder of each field was harvested (Figure 10C).

In processing the yield data, the combine test strips were further segmented into fifty discrete 10- x10-m grids and yields determined by averaging the combine yield values for each grid. For the complete-field harvest, the Spatial Analyst tool in ArcGIS was used to interpolate the yield data. In the spatial resolution analysis, yield point shapefile data were interpolated to a fixed 10- by 10-m grid using inverse-distance–weighted (IDW) interpolation with power set at 2 and number of neighbors set at 12 as per the method of Roel and Plant (2004). The average yields for each grid were calculated. A total of 504 grids each for the

LFI and Control fields were determined. By overlapping the yield and cut-or-fill map layers, relationships between cut-or-fill depths and rice yields were determined.

A. B. C.

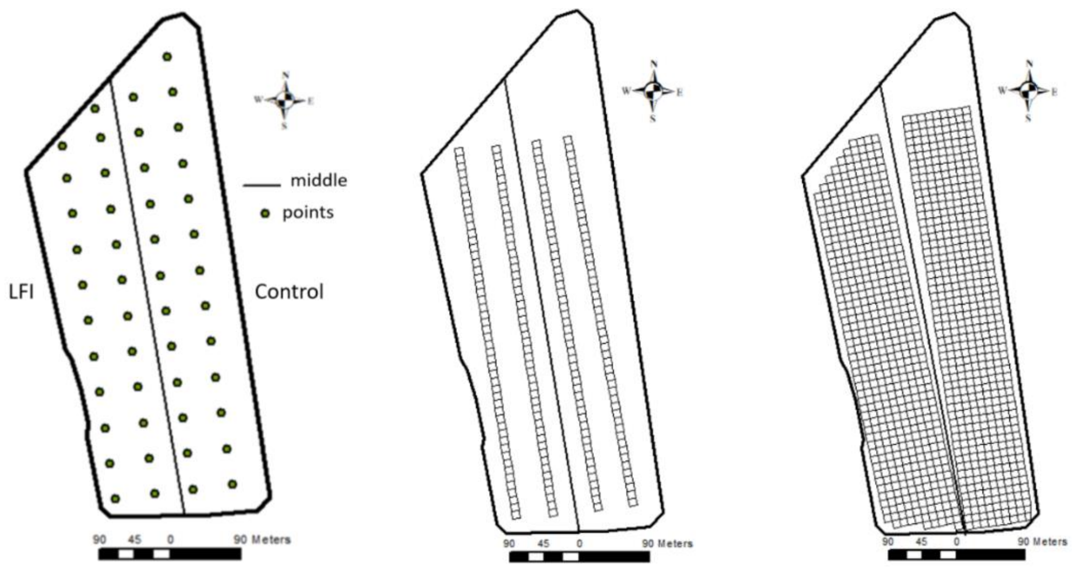


Figure 10: Three rice harvest methods, (A) manual harvest, (B) combine test strips, and (C) combine harvest of whole field, were used to compare rice yields of two land-leveling methods, land-forming for irrigation (LFI; left field) and a traditional (non-graded) rice levee leveling method (right field) commonly used in Uruguay and south America.

5.2.8 Statistical Analysis

Data were analyzed and visualized with R statistical software version 3.4.1 (R Core Team, 2021). Data normality was verified using the Shapiro-Wilk test. To compare means, a t-test was performed at a significance level of 95%. To determine correlations between the cut-or-fill areas and rice yield, Pearson's correlation coefficient test was used.

5.3 Results and Discussion

5.3.1 LFI field parameters

Figure 11 depicts how the LFI design was generated and implemented using the DEM of the 12-ha field site shown with 0.05-m contour lines (A), the WM-Fill LFI design project using 0.05-m contours (B) and corresponding cut-or-fill map used for the 6-ha LFI field (C). Five-centimeter contours are traditional rice flood depths used in the region and, thus, were used in the LFI field (left) and traditional rice levee leveling method that serve as the Control field (not shown). The LFI project estimated that an average of 104 m^3 soil per ha, totaling 604 m^3 soil, would be moved on the 6-ha field. The average and maximum cutting depths were estimated to be 0.03-m and 0.16-m, respectively. By comparison, the WM-form software estimated an average of 284 m^3 soil per ha (i.e., 2.7-times more) with an average of 0.07-m and maximum cut depth of 0.38-m, would be required if a 2-D laser leveling design with a *uniform field slope* of 0.13% had been used. Moreover, if the traditional rice levee leveling method (i.e., no alteration of the native topography using 0.05-m contours) was used on LFI field, 3.6-km of rice levees would be required whereas using LFI, total rice levee length was reduced 14% to 3.1-km and levee number reduced 28% from 25 to 17.

The above LFI are similar to LFI project simulations reported by Bueno et al. (2020). However, these authors estimated higher levels of soil movement (i.e., 146 m^3 ha^{-1}) as well as a 25% reduction in rice length and a 32% reduction in rice levee number. In the actual field implementation of a land-forming with varied slope project using GNSS-RTK System in areas having a field slope of about 0.15%, Quiros et al. (2020) reported values more in agreement with the present study in terms of soil movement (120 m^3/ha) and maximum cut depth (0.12-m).

5.3.2 Irrigation distribution uniformity

Figure 9 allows visual (i.e., qualitative) comparisons of the progression of floodwaters across the 6-ha LFI field, on the left side of image, with that of the 6-ha control field, right side, less than 24-hours after flood initiation which began on 24 November 2020. As can be seen, a shallow flood was established on over 90% of the LFI field compared to less than 50% on the control field. This could have positive agronomic benefits as decreasing the time required to establish a shallow rice flood improves both nitrogen use efficiency (NORMAN et al., 2009) and the activation of certain pre-emergence herbicides (SMITH et al., 2016).

Table 2 provides results from the manual flood depth measurements taken in December 2020, approximately two to four weeks after flood initiation on each field. Using coefficient of variation (CV) values as a measure of flood depth uniformity in the LFI and control fields, the former had nearly one-half the variation as that of the control field; this was true for depths along both the upper levee (26 vs. 46% CVs) and lower (18 vs. 32% CVs) levees. The lower CV values among flood depths in the LFI field indicates a more uniform water depth compared to that of the control field. Moreover, LFI resulted in average flood depths that are closer to the intended (i.e., theoretical) depth difference between the top and bottom flood depths within an individual. For example, the average within-paddy flood height difference (WPHD) for LFI was 0.032-m. This value is much closer to the 0.04-m target depth differential as compared to the control field value of 0.024-m (Table 2). The WPHD values of the LFI field also had a narrower range (0.03- to 0.15-m) than in the Control (0.01- to 0.13-m). Taken together, improvements in both the overall precision (i.e., uniformity) and accuracy (i.e., targeted flood depth) reveal the promise of LFI as flood uniformity and optimal depth management is associated with improved rice productivity (ANBUMOZHI et al., 1998). Irrigation data are in appendix 4.

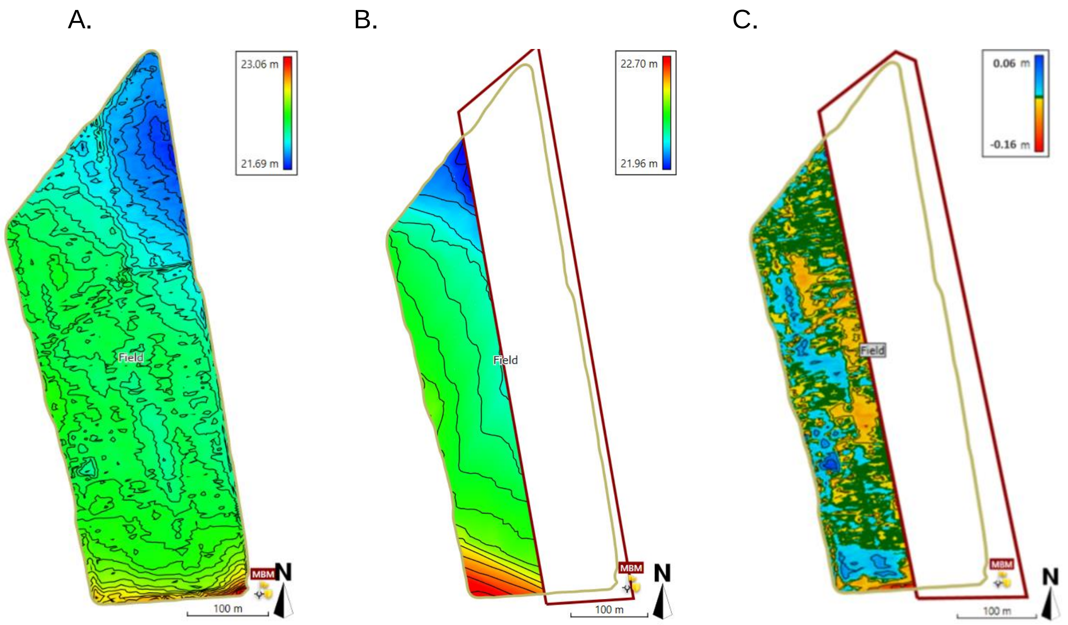


Figure 11: A digital elevation model (DEM) was created of the 12-ha study field (A) and used to develop a land-forming for irrigation (LFI) project with levee contours set at 0.05-m (B) with the resulting cut-and-fill map implemented on a 6-ha portion of the field (C). The topography of 6-ha portion on the right side of the field was unaltered and served as the study control.

Table 2: Coefficient of variation (CV) values and average within-paddy flood height difference (WPHD) resulting from land grading for irrigation (LFI) relative to control rice field using tradition levee leveling.

	Coefficient of Variation (%)		Within-paddy flood height difference (WPHD, m)		
Field Grading Treatment	Upper Paddy	Lower Paddy	Average	Min Value	Max Value
LFI	26.0	18.1	0.032	0.03	0.115
Control	45.6	31.7	0.024	0.01	0.13

Fangmeier et al. (1999) used to models to demonstrate the importance of the precision (i.e., relative levelness) of surface-irrigated fields in terms of irrigation wetting front advancement and overall efficiency. The authors found that "efficiency and uniformity decreased substantially when standard deviations of the soil surface elevations were greater than 20 mm." Similarly, modeling of Bai et al. (2011) showed that "the effect of the spatial variability of microtopography become more obvious when S_d (land leveling precision) was more than 1 cm." While the irrigation distribution uniformities of LFI designs will never match those of level-basin fields, results of the present study show significant improvements relative to a traditional levee leveling practice.

5.3.3 Crop Productivity between LFI and Control

Table 3 compares rice yields determined for the LFI and Control fields using three harvest methods (i.e., manual harvest; combine test strips; combine harvest of whole field). Both the LFI and Control treatments exhibited high grain productivity in both growing seasons, ranging from 10,613 and 13,014 kg ha^{-1}. The manual harvest method measured average yields of 12,295 kg ha^{-1} for LFI and 13,014 kg for the Control in the 19/20 season and averages of 10,613 kg ha^{-1} for the LFI and 10,684 kg ha^{-1} for the Control in the 20/21 season. Using the manual harvest results, no yield differences ($\alpha = 0.05$) were detected between the LFI and control treatments.

Table 3: Average rice yields resulting from the manual harvest, combine test strips, and combine harvest of whole field for LFI and Control fields.

Rice Harvest Method	Season	Treatment	N	Mean kg ha $^{-1}$	P< 0.05	df
Manual Harvest	19/20	LFI [a]	23	12,295	NS	46
		Control [a]	25	13,014		
	20/21	LFI [a]	23	10,613	NS	46
		Control [a]	25	10,684		
Combine Test Strips	19/20	LFI [a]	100	11,182	NS	198
		Control [a]	100	11,494		
	20/21	LFI [a]	100	11,150	NS	198
		Control [a]	100	11,227		
Combine Whole Field	19/20	LFI [a]	504	12,560	NA	1006
		Control [b]	504	11,696		
	20/21	LFI [a]	504	10,774	NA	1006
		Control [b]	504	11,387		

NS = non-significant difference; NA = not applicable.

Figures 12A and 12B show the yield maps derived from the combine test strips for the LFI (A) and Control (B) fields, for the seasons 19/20 and 20/21, respectively. The average yields in the 19/20 season were 11,182 and 11.494 kg ha^{-1} for LFI and the control, respectively. For the 20/21 season, the average yields were 11,150 and 11,227 kg ha^{-1} for LFI and the control, respectively. In this comparison, even when the number of data points is almost four-times larger (i.e., 200 vs 48) than that of the manual samples, no yield differences (P>0.05) between LFI and control were detected (Table 3).

Yield maps resulting from combine harvests of the whole LFI (Figure 12C) and Control fields (Figure 12D) with results displayed for the 19/20 and 20/21 growing seasons, respectively. No statistical tests were made on the whole-field yields owing to the lack of independence among the data points. However, these registered levels of productivity correspond with the total rice harvested in both treatments. Table 3 shows that the average yield in the 19/20 season were 12.560 kg ha^{-1} for the LFI and 11.696 kg for the control system, while for the 20/21 season the average was 10.774 kg for the LFI and 11.387 kg for the control system. In 19/20, average rice yield for the LFI system was 7% higher than the Control while in 20/21 the Control field performed about 5% better than LFI, indicating that potential causes of this difference cannot be associated with this land-forming alteration.

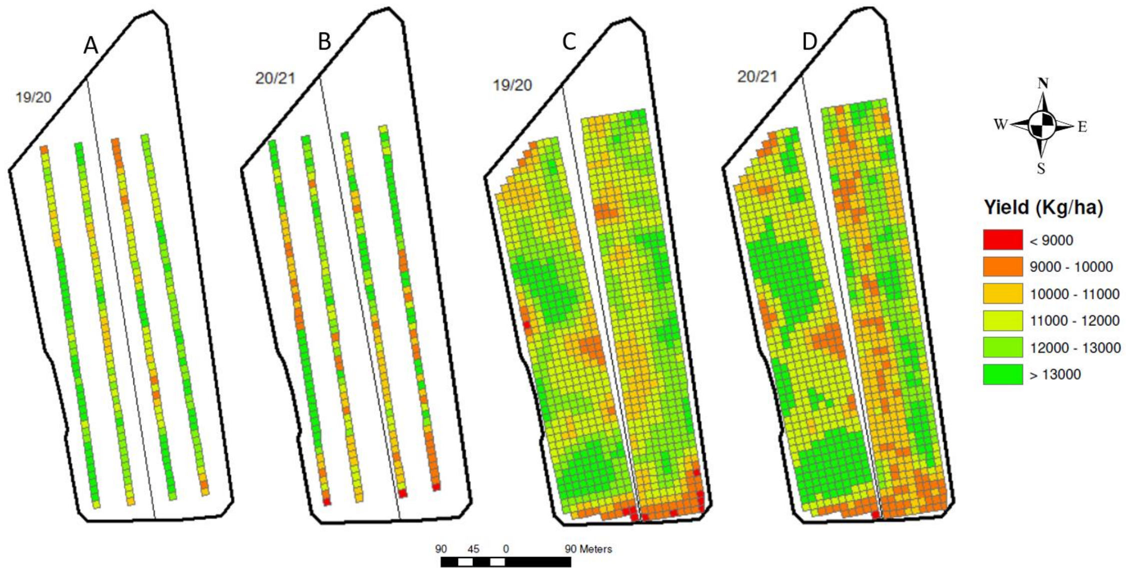


Figure 12: Yield maps derived from the combine test strips for the LFI (A) and Control (B) fields compared to yield maps produced using combine harvests of the whole LFI (Figure C) and Control fields (Figure D) with results displayed for the 19/20 and 20/21 growing seasons, respectively.

Highly variable results have been reported regarding the effects of land leveling on rice yields. Quiros et al. (2020) reported productivity gains of nearly 80% after applying land leveling with variable slope while Simmonds et al. (2013) reported no difference in rice yield due to land leveling. Devkota et al. (2021) reported that for rice-wheat and maize-wheat cropping systems in eastern India, land leveling to 0.1% slope increased productivity by 10% compared to zero-grade systems while a study in the Philippines found no effect of gradient (0% vs 0.1%) on rice grain yield (EVANGELISTA, 2019). Still more, the results of Naresh et al. (2014) found that laser leveling significantly affected the yield and yield components of rice, wheat, and sugarcane. Much of the variation in outcomes can be attributed to the extent to which the soil is altered when achieving the desired field slope(s).

5.3.4 Soil alteration (cut-and-fill) effects on rice yield

Again using the three harvest methods (i.e., manual harvest; combine test strips; combine harvest of whole field), the relationships between rice grain yield and cut-and-fill areas in the LFI treatment were evaluated for both growing seasons. Figures 13A–13I depict relationships existing between the extent of soil alteration (*SA*) (i.e., cut or fill) and the deviation of rice yields at cut-or-fill sites from field averages. These yield deviations were calculated as follows:

$$Yield\ Deviation\ (\%) = [(Sample\ Yield - Field\ Average\ Yield) \div (Field\ Average\ Yield)]x\ 100$$

[1]

A positive yield deviation represents an above average rice yield while a negative value represents a below average yield. A positive cut/fill value represents an area receiving soil (i.e., fill) while a negative value represents an área of field losing soil (i.e., cut). Table 4 presents the corresponding equations, Pearson´s correlation coefficients and level of significance for each of the associations displayed in Figure 13. In all evaluation levels and seasons, a relationship of increased productivity in the fill zones (positive values on the X axis) and a decrease in yield in the cut zones (negative values on the x axis) were observed.

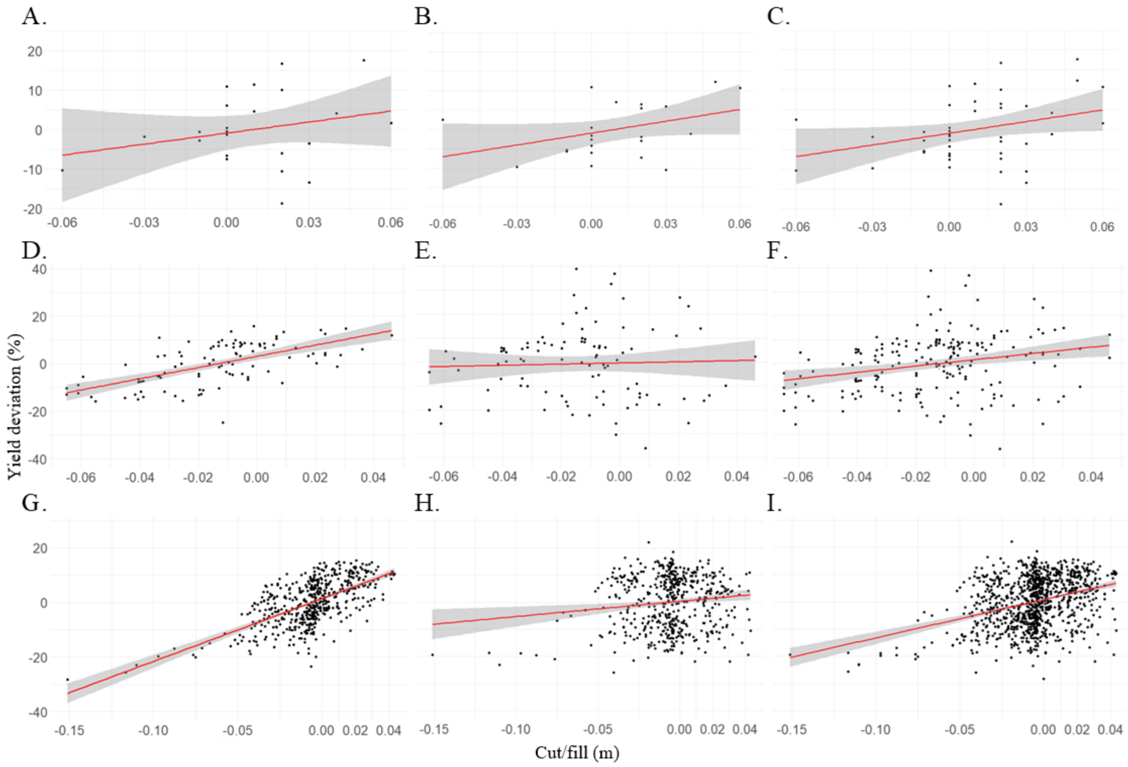


Figure 13: Correlations of deviations from the mean rice yields (y-axes) with soil cut-or-fill locations (x-axes) when a land-forming for irrigation (LFI) design was imposed on a 6-ha field. Graphs A-D-G are 2019/20 data, B-E-H are 2020/21 data, and C-F-I are pooled data. Graphs A-B-C, D-E-F, and G-H-I represent the manual harvest, combine strip test, and combine harvest of whole field results, respectively.

When comparing only manually-harvested rice sample results (Figure 13 A, B), the range of yield deviations from the different levels of soil alteration was limited. Using this appro, yield variability measurements were restricted to areas having between -0.06 (cut) and +0.06 m (fill) with yield deviation of ±10%. For this reason, no significant associations were detected between soil alteration (SA) and productivity for the individual growing seasons. Only when data from both seasons were pooled (Figure 13 C) was a significant ($\alpha < 0.05$) relationship found.

When the combine test strip yield data (Figures 12 A and B) were overlayed with corresponding LFI cut-or-fill map (Figure 11 C), the larger sampling areas resulting in a significant correlation in 2019/20 (Figure 13 D) but a non-significant correlation in 2020/21 (Figure 13 E). The latter result suggests that soil alterations effects may diminish after one season of rice production. When data from both seasons were pooled, a significant relation was detected (Table 4).

When the combine harvest of whole field results (Figure 12 C and D) were overlayed with the corresponding LFI cut-or-fill map values (Figure 11 C), the complete variability in rice yield is capture, ranging from the highest cut (-0.16 m) to the highest fill (+0.05 m) (Figures 13 G and H). A larger impact on yield effects can be observed at this level with reduction up to 30%. Pooling both years of data (Figure 13 I), a significant relationship between soil alteration and yield deviation was observed (Table 4). As was found with the combine test strips in the second year, this association was less evident, again suggesting that land forming were starting to be ameliorated by the second year. When data from both seasons are pooled together a significant relation was detected (Table 4).

In analyzing Figure 13, particularly Fig. 13 that is the most comprehensive, a clear pattern emerges that shows soil cuts greater than 0.05-m always had a negative impact on rice yield. Conversely, in areas of the field that either do not have soil topography alteration or where filled the effect on yield can be negligible, positive or negative, suggesting that other factors can be influencing on this relationship. The largest soil cut depth used in the LFI was -0.16-m. Using this as the x-value in Equation 9 of Table 4, a yield reduction of 30% relative to the field average is predicted. This corresponds to what was observed in the yield maps and was limited to a small portion of the field. Using this same equation indicates that yield reductions larger than 10% will be obtained when the soil cut is deeper than 0.06-m, suggesting that this can be a good indicator to use when soil alteration alternatives are planned for this lowland soil. Similar results were found by Winkler (2018) and Muñoz (2019) in areas where land leveling with uniform slope was performed using the laser system. Both authors demonstrated that soil cuts deeper than 0.05-m reduced rice yields while cuts reaching 0.3-m reduced rice yields by up to 20% below the average. Walker et al. (2003) also found that reductions in rice yield were strongly related to the amount of soil moved during land leveling, although the authors were unable to conclusively show that the reductions was due to reduced nutrient availability. The average soil cutting depth in the present LFI study was 0.03-m, corresponding to a 3.5% yield reduction as per Eqn. 9 (Table 4) compared to the traditional rice levee leveling control hich had no alteration of soil topography.

Table 4: Effect of harvest method (i.e., sample size) correlationships between rice yields (dependent variable) and cut-or-fill soil depths (independent variable) resulting from land forming of a 6-ha lowland soil field.

Harvest Method	Growing Season	Sample Size (N)	Equation No.	Linear Equation	Correlation Coefficient (r)	P-value
Manual Harvest	19/20	48	1	-0.89+0.93x	0.25	NS
	20/21	48	2	-0.98+100x	0.37	NS
	19/20 and 20/21	96	3	-0.94+98x	0.30	*
Combine Test Strips	19/20	100	4	3.1+240x	0.62	***
	20/21	100	5	0.97+74x	0.15	NS
	19/20 and 20/21	200	6	2+160x	0.26	***
Combine Whole-Field	19/20	504	7	1.4+230x	0.63	***
	20/21	504	8	0.34+56x	0.12	*
	19/20 and 20/21	1008	9	0.81+140x	0.34	***

NS = not different at α=0.05; (*) = $P<0.05$; (***) = $P < 0.001$.

5.4 Conclusions

This was the first time an LFI project was implemented for rice production in Uruguay. Preliminary results from this study are encouraging. This study shows that the incorporation of three novel technologies, global navigation satellite systems (GNSS) using real-time kinematic (RTK) correction and specialized topographic software, create new options for land leveling in three-dimensions. The LFI design used here resulted in minimal soil disturbance while improving irrigation and drainage conditions and achieving the similar rice yields as a traditional rice levee leveling system. Traditional levee systems also require considerable soil disturbance and result in less-than-optimal irrigation distribution uniformity as demonstrated here. The yield reductions associated with the deeper soil cutting depths used in this LFI design tended to diminish by the second year of rice production after grading. This practice could potentially impact a large area of rice production not only in Uruguay but across rice growing regions of South America where much of the pasture and soybean grown in rotation with rice are not typically irrigated owing to poor surface drainage and resulting waterlogging associated with native topography of lowland soils.

6. Capitulo 2 - Land Forming with Furrow Irrigation: impacts on soybean productivity in lowlands

6.1 Introdution

Continuing population and consumption growth will mean that the global demand for food will increase for at least another 40 years (GODFRAY et al., 2010). This represents a challenge for agriculture, and also an opportunity for countries that have agriculture as their economic base. In Uruguay, the productive system in the lowlands of the Mirim Lagoon basin is basically constituted by the rice-pastures rotations, the sustentable intensification with others crop rotations have a positive impacts on resource use efficiencies, yields, and environmental indicators (PITTELKOW et al., 2016).

Successive monoculture for a long time increases the level of weed infestation, especially weedy rice, making rice cultivation unfeasible in several places. In this scenario, soybean rotation is essential for significantly reducing weedy plants and irrigated rice cultivation (ULGUIM et al., 2018). The sustentable intensification alternatives exist for rice cropping systems in lowlands can improve energy use efficiency and return on investment like rice-soybeans (MACEDO et al., 2021). The intensification of land use like rice-soybeans systems in Arkansas-USA and Brazil (BRYANT et al., 2012; MARTINS et al., 2016) are examples that can lead to this increase.

In lowland soils the natural deficient drainage caused by a dense and impervious B horizon makes these soils well suitable to irrigated rice production (Lima et al., 2009). Being characterized by mostly flat and roughness surface (KAMPHORST et al., 2000) with low slope, approximately 0.1% (BORSELLI; TORRI., 2010; WINKLER et al., 2018), where hydromorphic soils with low hydraulic conductivity predominate.

Growing upland crops (such as soybean) in lowland environments is challenging. The drought stress (Heatherly and Spurlock., 1993) and waterlogging (BORTOLUZZI et al., 2018; SARTORI et al., 2016) in lowlands promote yield loss in soybean. Thus, successful adoption of alternative agronomic crops into rice cultivated under lowland conditions requires that both drainage and irrigation issues be successfully addressed (BUENO et al., 2020).

The majority of soybean crops in the lowlands of Uruguay are cultivated in a original topography, being predominantly flat, with the presence of spots where there is superficial waterlogging, being difficult to drain (Figure 14). In the lowlands, dry crops, mainly soybeans, but also corn, in recent years have become a great alternative for producers to rotate crops, for agronomic benefits and market values that are becoming more attractive.

Figure 14: Photograph of a system traditionally used for soybean production on lowland soils in Uruguay and Southern Brazil. It is possible to see spots with surface water storage.

One way to promote adoption of alternative crops in lowlands is through the use of raised seedbed crop system that can improve poor drainage in lowlands (GOLLO et al., 2020; CASSOL et al., 2020), and also improves the physical characteristics of the soil and allows the use of a furrow irrigation system (GIACOMELI et al., 2016; SARTORI et al., 2016). Alternate furrow irrigation reduces water application without affecting yield and thereby leads to more efficient water use (GRATEROL et al., 1993). However, the furrow system, in order to present a better performance in terms of drainage and irrigation, needs a correction of the micro relief, which, through land leveling, makes the soil surface ideal to obtain a better crops perfomance with furrow system.

The operation of land-leveling (i.e land grading) is used in agriculture to modify the soil surface to standardize its slope (BRYE et al., 2006), correct irregularities in soil surfaces to make agricultural activities such as suface drainage and irrigation more efficient, facilitate the distribution of water and improve field conditions for other agricultural practices, thus providing a uniform distribution and water savings (BAI et al., 2017), and also enhances the efficiency of the other farm inputs (JAT et al., 2009).

Thus, leveling may constitute a viable practice to improve surface drainage and irrigation in the lowlands of southern Brazil (WINKLER et al., 2018), fostering broader rotational options for producers. Caution must be used, however, in applying the practice because leveling that results in cuts exceeding 10-cm in shallow soils may cause problems (AQUINO et al., 2015), such as impaired soil fertility (Walker et al., 2003), increased compaction, and changes in microbial community structure (BRYE et al., 2006). Additionally, at current leveling costs of approximately USD 1 per cubic meter in southern Brazil, extensive soil movement makes leveling uneconomical (BUENO et al., 2020).

One such land leveling option is Land leveling with variable slope (i.e land forming), here is the tratament Land Forming with Furrow Irrigation (LFFI). Consists of smoothing the soil surface with automated land leveling equipment. This equipment can execute the software prescription that indicates the areas of the field that need to be cut or filled. All depressions and high points of the field are eliminated, allowing more uniform flow of water.

This alternative method, explained by Bueno et al. (2020), may require smaller amounts of soil to be moved and, consequently, shallower cutting depths than laser-leveling, while still improving irrigation and drainage compared to 2-D laser leveling. It may also reduce soil disturbance associated with traditional levee-based leveling systems used in rice growing regions of Uruguay and South America (Lowland regions).

It is anticipated that precision grading will be increasingly adopted in Uruguay and South America. However, to better characterize the differences in yield, yield monitors may be required to capture the effects of grading at field scales (COOK; BRAMLEY, 1998; BULLOCK et al., 2019) necessary to assess the crop yields at field-scale, and soil electrical conductivity were used to better describe the effects of sodium (Na) in productivity variability (KACHANOSKI et al., 1988; WILLIAMS; HOEY, 1987).

Identifying new land forming techniques, with regard to improve the flow rates and application time for irrigation, without waterlogging, is necessary for adequate supply of water to plants and a sustainable soybean farming in that it optimizes the use of resources. The hypothesis of this study is that LFFI will allow for improved irrigation distribution uniformity with little negative impacts on crop productivity relative to a traditional levee-leveling practice. The objective of this study was to evaluate soybean yields in a LFFI precision-graded field and in a traditionally field (control).

6.2 Material and Methods

6.2.1 Experimental area

The experiments were carried out in a 10 ha experimental area (Figure 15) located in Paso de la Laguna, Treinta y Tres department, in the Eastern region of Uruguay (PdL: Lat: −33.16S, Long: −54.10W), on a typical soil type of the main rice producing region of Uruguay, with limited radicular depth (20 - 30 cm), by the presence of a subsurface soil horizon with high content of clay. Soil type was a Planosol of “La Charqueada” soil unit (MGAP, 1976). Mean annual rainfall at the site is 1360 ± 315 mm; annual total potential evapotranspiration is 1138 ± 177 mm; mean monthly temperature is 22.3 ± 0.85+C (summer) and 11.5 ± 0.82+C (winter). This experiment was conducted throughout two soybean growing seasons of 2019/20 - 2020/21, The area was fallow for 4 years, with rice being the last crop cultivated, and then keeping to natural grassland. The experimental field was divided into two areas: 5 ha where the land forming with furrow irrigation (LFFI) model was performed (LFFI half); and 5 ha where there was no alteration of the land topography (Control half), Figure 15. The experimental area is located near Rio Grande do Sul – Brazil, where there is a very similar productive crop system. The chemical and physical characterization of the soil is in Appendix 3.

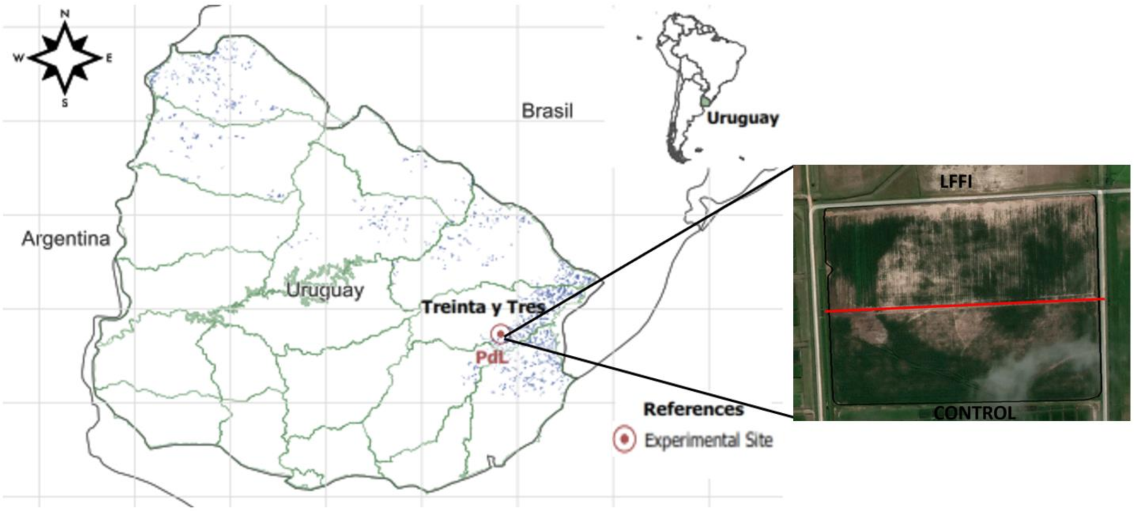


Figure 15: The inset shows the commercial-scale 10-ha field, located in Paso de la Laguna (PdL) of the Instituto Nacional de Investigación Agropecuaria (INIA), that was equally divided into the Land-Forming with furrow Irrigation (LFFI) field and non-graded field (Control) used in this study (Uruguay map courtesy of Federico Campos).

6.2.2 Digital Elevation Model and Land-forming with Furrow Irrigation (LFFI) Design

A planimetric survey of the 10-ha field was conducted using a tractor equipped with a monitor and GNSS receiver antenna with RTK base station (AZIZ et al., 2009). The resulting elevation data were processed using WM-Form software to generate a digital elevation model (DEM) for the surface. The calculations for LFFI design were performed using WM-Form software using a cut/fill ratio of 1.2 (GAMERO; BENEZ, 1989). This design was generated in the sub designing areas mode and allows the user to choose the direction and the minimum magnitude of a preset slope. Both cut and fill volumes are balanced in a way that depends on factors such as soil compaction. These calculations were performed using 3-m grids and a balanced-soil movement criterion, the minimum slope of 0.05 % was employed as demonstrated by Bueno et al. (2020). For the realization of the soil movement in the field, a tractor equipped with a monitor where the LFFI project was inserted, and also equipped with a land plane were used, thus following the cut and fill project pre-established by the software, the tractor-plane set when moving through the field, carried soil from the cutting to the fill regions, this being done automatically by the plane through the use of a valves and a controller module.

6.2.3 LFI Project Implementation

During the spring of 2019 the LFI design was uploaded onto a computer system of a tractor (New Holland, TM 7020) equipped an earth-moving scraper (Los Antonios, 4 m of width). The scraper was equipped with module and valves to automatically remove (cut) and deposit (fill) soil as per the design.

6.2.4 Agronomics

On 05 December 2019 and 11 November 2020, the LFFI and Control fields were planted with a 60i62 ipro DM soybean cultivar, using a Stara model Cinderela (https://www.stara.com.br/) and 45-cm row spacing. Both sowing dates fell within the window for optimal soybean planting in Uruguay. Land preparation, weed control, all were performed on dry soil. Nitrogen fertilizer was applied pre-flood (dry soil) and at panicle initiation (flooded soil). Other key agronomic practices and dates are presented in Table 5.

Table 5: General management practices by season.

	Season	
	2019/2020	**2020/2021**
Sowing date (seeds per meter)	Dec 05 (20)	Nov 11 (20)
Rainfall (mm)	172	212
KCL fertilization (kg ha^{-1} K_2O)	Nov 16 (240)	Nov 04 (240)
Emergence date	Dec 6	Nov 26
Fungicide application (ml ha^{-1})	Dec 4 (250)	Nov 23 (300)
NPK line (kg ha^{-1} N)	Jan 5 (5-25-25)	Dec 18 (5-25-25)
50% flowering date	Feb 9	Feb 1
Harvest date	Apr 30	Apr 26

6.2.5 Geographic information systems (GIS) and yield data

For the yield comparison between the LFFI half and the Control half and association between cut/fill and yield in the LFFI treatment the machine-harvested combine strips was performed, the fields were harvested using a combine harvester (New Holland, TC5070 model) equipped with an AgLeader yield monitor (model PF 3000; Ames, IA, USA), global positioning system (GPS), and a 5-m wide draper header.

At the start of each harvest season, the yield monitor was calibrated as per Griffin et al. (2008) using a grain cart with certified scale. Yield data (yield, grain, moisture, longitude, and latitude) were downloaded and imported into Ag Leader

Spatial Management System (SMS) software geographic information system to construct yield maps. The data were analyzed and processed using ArcGIS version 10.6 software (ESRI, Redlands, CA, USA). Outliers in the yield data were removed as per Vega et al. (2019).

The method we chose utilized the Spatial Analyst tool in ArcGIS to interpolate the yield data. In the spatial resolution analysis, yield point shapefile data were interpolated to a fixed 10- by 10-m grid using inverse-distance–weighted (IDW) interpolation with power 2 and number of neighbors 12, following same procedure used by Roel and Plant (2004). A 10x10m grid was generated where the average of the yield that were within each corresponding grid was obtained.

6.2.6 Collection and comparison of yield with ECa and Sodium (*Na*)

Apparent soil electrical condutivity (ECa) was determined through the Veris equipment, where the passes were performed every 6 m of distance throughout the field (10ha). VerisEC soil electrical conductivity sensor is used for detecting the ability of soil in conducting electricity. In the Veris Soil EC Mapping System the electrodes are rotating discs placed 6cm into the soil. As the cart is pulled through the field, one pair of electrodes passes electrical current into the soil, while two other pairs of electrodes measures the voltage drop. The device measures the apparent electrical conductivity of the soil in depths of 0–0.3 m and 0– 0.9 m at the same time. In this study data from the depth of 0– 0.3 m was used, as the reference soil samples were also collected from this depth.

To determine the sodium (*Na*) content, 30 soil samples were taken from the entire field, each with 3 subsamples, totaling 3 samples per hectare. In Figure 16B is the grids used to perform the correlation between yield with ECa30 and *Na*, it was used the complete-field harvest, a total of 520 grids each for the LFFI and Control fields were determined. To correlate the ECa30 with productivity, the ECa with 30 cm of depth (ECa30) was used, and to correlate Eca30 with *Na*, 30 soil samples was used with the correspondent value of ECa30 to the grid. By overlapping the yield and ECa30 map layers, relationships between yields, *Na* and ECa30 were determined.

6.2.7 Soybean Yields comparison

For comparison among treatments yields, harvest combine stripes with 130 meters long by 10 meters wide were performed, which represents 0.13 hectares. Each strip generate a 13 “grids” of 10x10 meters each. In each grid, the average yield of the points were calculated. Four stripes were performed each year (Figure 16A), two in the LFFI half and two in the Control half.

The combine was used to harvest each field in two ways: First, four test strips, each 10- x 130-m (0.13-ha), were harvested in each field. Each strip was made by making two passes with the combine down the length of each field (Figure 16A). Secondly, the remainder of each field was harvested (Figure 16B).

In processing the yield data, the combine test strips were further segmented into fifty discrete 10- x10-m grids and yields determined by averaging the combine yield values for each grid. For the complete-field harvest, the Spatial Analyst tool in ArcGIS was used to interpolate the yield data. In the spatial resolution analysis, yield point shapefile data were interpolated to a fixed 10- by 10-m grid using inverse-distance–weighted (IDW) interpolation with power set at 2 and number of neighbors set at 12 as per the method of Roel and Plant (2004). The average yields for each grid were calculated. A total of 504 grids each for the LFFI and Control fields were determined. By overlapping the yield and cut-or-fill map layers, relationships between cut-or-fill depths and rice yields were determined.

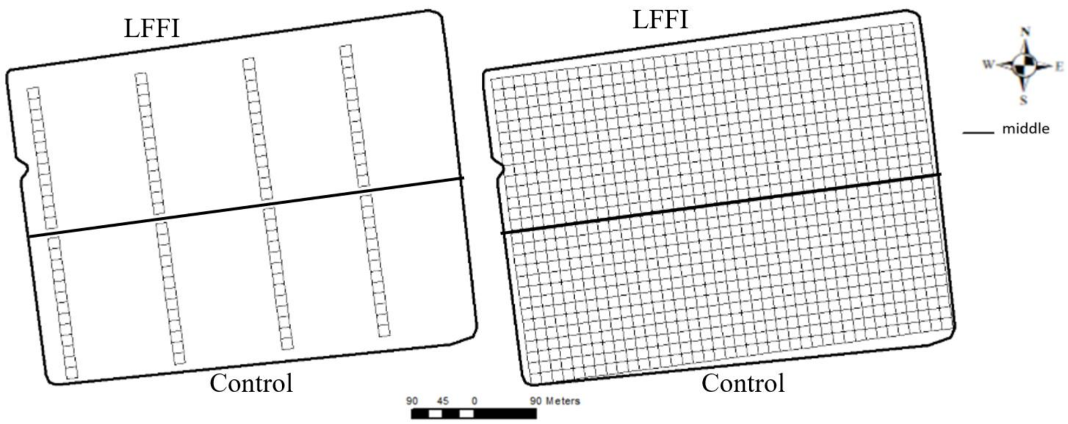


Figure 16: Two soybean harvest methods, (A) combine test strips, were used to compare soybean yields of two land-leveling methods (LFFI; upper field) and a traditional (non-graded) soybean crop (botton field) commonly used in Uruguay and south America, and (B) combine harvest of whole field, were used to compare soybean yields, Eca30 and *Na* between the two methods.

6.2.8 Statistical Analysis

Data were analyzed and visualized with the open-source statistical software R 3.4.1, and data normality was verified using the Shapiro-Wilk test. To compare means a Ancova-test was performed at a significance level of 95%. And for the correlation between productivity and Eca30 and *Na*, the Pearson test was used.

6.3 Results

6.3.1 Land forming with furrow irrigation (LFFI) design

After the plan altimetric survey a digital elevation model (DEM) was generated and for Control the contour lines every 0.05 m of vertical interval are displayed (Figure17A), and simultaneously the LFFI Project proposal (Figure 17B) with the same vertical interval. In order to carry out the proposed LFFI project a soil movement of 108 m^3 ha^{-1} was determined, totaling 540 m^3 of soil moved on this half. The depth of cut was in average 0.02 m, with a maximum cut of 0.08 m (Figure 17C). By comparison, the WM-form software estimated an average of 208 m^3 soil per ha (i.e., 2-times more) with an average of 0.05-m and maximum cut depth of 0.14-m, would be required if a 2-D laser leveling design with a *uniform field slope* of 0.07% had been used.

If the Traditional Leveling with no alteration of the topography would be applied in this half of the field (LFFI) would have the presence of four depressions (where surface water storage occurs after intense rainfall) and three locations with high altimetry (where the contours are polygons), these places make it difficult, or even do not allow the passage of water in the furrow. However, when the LFFI was applied there was no depressions or locations with high altimetry.

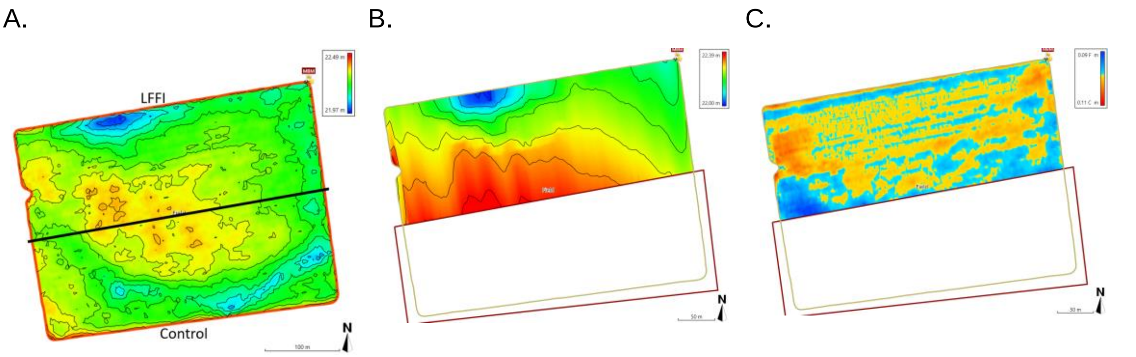


Figure 17: A digital elevation model (DEM) was created of the 10-ha study field (A) and used to develop a land-forming for irrigation (LFFI) project with levee contours set at 0.05-m (B) with the resulting cut-and-fill map implemented on a 5-ha portion of the fie field (C). The topography of 5-ha portion on the right side of the field was unaltered and served as the study control.

6.3.2 Sodium effects on productivity variability

Yield maps resulting from combine harvests of the whole field (Figure 18A) with results displayed for the 19/20 growing season, the values ranged from 963 kg to 4275 kg ha^{-1}, with an average of 2100 Kg ha^{-1}. In the LFFI treatment, it is possible to visualize a zone where the highest values are concentrated. Figure 18B shows the map of sodium (*Na*) with values ranging from 0.53 to 2.65 meq $100g^{-1}$, with an average of 1.10 meq $100g^{-1}$.

Figure 18C shows the apparent electrical conductivity map (ECa30) of the soil at a depth of 30 cm. The ECa30 values ranged from 36.4 to 109.2 mS m^{-1}, with an average of 65.8 mS m^{-1}, in the map these values start from 70 mS/m, due to the fact that in the decision tree (Figure 20) the first node is precisely the ECa30 with a value of 69.8 mS m^{-1}, for the LFFI tratment there was 287 grids with ECa30 above 70mS m^{-1}, and for the control tratment there are 118 grids.

In Figure 18B it is possible to verify that there is a zone where there is a high concentration of sodium, and this is directly associated with the ECa30 map (Figure 18C), however it is inversely correlated with the productivity map (Figure. 18A), that is, the higher the sodium (*Na*) and ECa30 values, the lower the productivity is.

A. B. C.

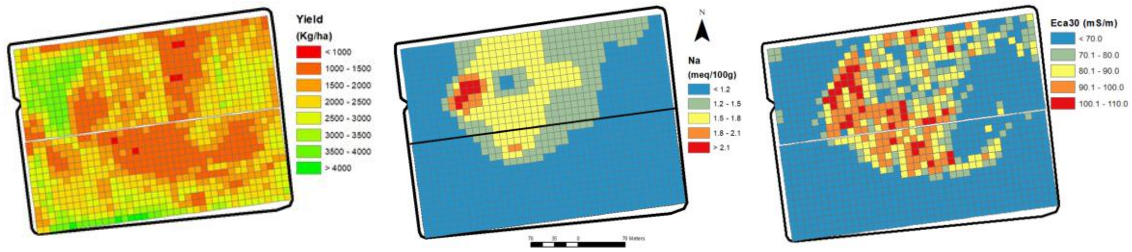


Figure 18: (A) Yield map for the whole field for the season 19/20, (B) Sodium (*Na*) content in the soil, (C) Apparent soil electrical condutivity with 30 cm Deep soil (ECa30) for the whole field.

Figure 19A depict relationships existing between the soybean yield and ECa30 of whole field, a negative correlation can be observed, that is, as the ECa30 values increase, soybean productivity is reduced. The mean ECa30 was 72.2 and 60 mS m^{-1} for the LFFI and Control treatments, respectively, whereas the total mean was 66 mS/m. The average total productivity was 2100 kg ha^{-1}, to the points that was above 94 mS m^{-1}, all deviations for productivity were negative. Although it showed low productivity values (964 kg ha^{-1}), much of which was due to a specific location in the field where ECa30 was high (> 70 mS m^{-1}), high yield values were also obtained (4275 kg ha^{-1}) in areas where ECa30 was low (< 70 mS m^{-1}).

In Figure 19B there is relationships existing between the sodium (*Na*) and ECa30 of whole field, where had a positive correlation, low ECa30 values (36.4 mS m^{-1}) where *Na* was low, and high ECa30 values were also obtained (109.2 mS m^{-1}) in areas where ECa30 was high.

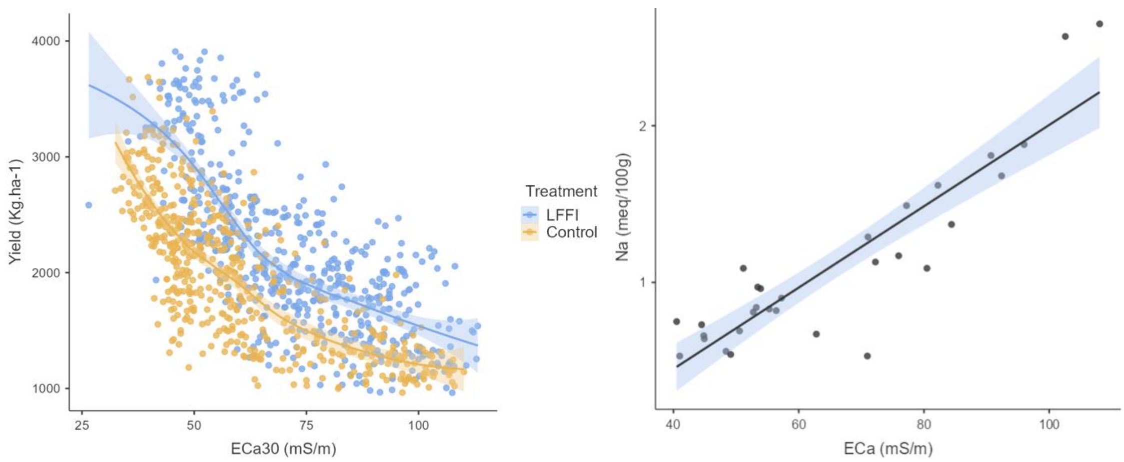


Figure 19: Figure A (left) is the correlations of deviations from the mean soybean yields (y-axes) with soil Eca30cm locations (x-axes). In figure B (right) is the cumulative distribution function of Eca30, for LFFI and Control for the 19/20.

Table 6 shows the correlation between yield and Eca30, for the LFFI treatment the fitting straight line (eq. 1) presented an R^2 of 0.57, the Pearson correlation coefficient (r) was -0.66, being a strong negative correlation, and for the Control (eq. 2) the R^2 was 0.61 and the r was -0.68, also showing a strong negative correlation. In the correlation between *Na* and Eca30, the fitting straight line (eq. 3) presented an R^2 of 0.81 and an r of 0.90, being a positive and very strong correlation.

Table 6: Correlationships between soybean yields (dependent variable) with Eca30 and *Na* (independent variables).

Correlation	Treatment	Equation No.	Equation (Eq.)	R2	Correlation Coefficient (r)	P - value
Yield – Eca30	LFFI	1	$0.42x^2 - 90.39x + 6338.20$	0.57	-0.66	< 0.001
	Control	2	$0.35x^2 - 72.66x + 49.30$	0.61	-0.68	< 0.001
Na – Eca30	Whole Field	3	$31.17x + 30.91$	0.81	0.90	< 0.001

6.3.3 Crop Productivity

6.3.3.1 Factors affecting variation in on-farm soybean yield

The regression trees (Figure 20) analysis for the soybean yield from the combine test strips, as a function of treatment (LFFI and Control), grown season and ECa30, had four terminal nodes with three splitting nodes, represented by the value relative to the average (1754 Kg ha-1). Where in the first node the parameter for the division of the tree was the ECa30, resulting in two branches, the grids that presented values of ECa30 below 69.8 mS m^{-1} went to the right side of the tree, with the value 1.17 times the average and presenting 118 grids. To the left of the tree are the grids with ECa30 values above 69.8 mS m^{-1}, with a value of 0.778 times the average, presenting 90 grids.

For the next node (ECa30 < 69.8 mS m^{-1}), the parameter used was the treatment, and to the left the Control treatment obtained 1.06 times the average, and the LFFI treatment showed 1.35 times the average, being 44 grids (21.2%), this was the highest productivity average. To the node where the ECa30 < 69.8 mS m^{-1}, control treatment presented 0.595 times the average, being 31 grids (14.9 %), which is the lowest value, whereas the LFFI treatment presented 0.874 times the average, being 59 grids (28.4 %).

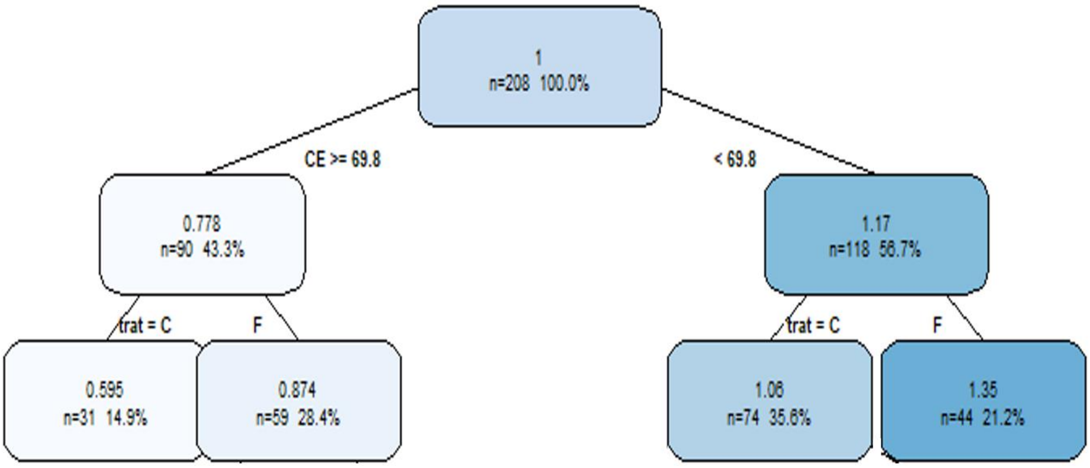


Figure 20: Decision tree for combine test strips.

6.3.3.2 Crop yield between treatments

Table 7 compares soybean yields determined for the LFFI and Control fields using combine test strips method. Both the LFFI and Control treatments exhibited low grain productivity in both growing seasons, ranging from 1421 and 1988 kg ha^{-1}, this is because sodium effect. For the 19/20 season the yield mean was 1988 and 1784 Kg ha^{-1} for the LFFI and Control, respectively. And for the 20/21 season the yield mean was 1822 and 1421 Kg ha^{-1} for the LFFI and Control, respectively. For the two crops season there was a significant difference in grain yields.

Table 7: Average soybean yields resulting from the combine test strips for LFFI and Control fields.

	season	Half	n	Mean kg ha^{-1}	P< 0.05	df
Stripes	19/20	LFFI [a]	52	1988	0.001	102
		Control [a]	52	1784		
	20/21	LFFI [a]	52	1822	0.001	102
		Control [a]	52	1421		

df = degrees of freedom

Figure 21A and 21B show the yield maps derived from the combine test strips for the LFFI (A) and Control (B) fields, for the seasons 19/20 and 20/21, respectively. The average yields in the 19/20 season were 1988 and 1784 kg ha^{-1} for LFFI and the control, respectively. For the 20/21 season, the average yields were 1722 and 1421 kg ha^{-1} for LFFI and the control, respectively. In this comparison show that have a significant yield difference (P<0.05) between LFFI and control were detected (Table 7) for the 19/20 and 20/21 grow seasons.

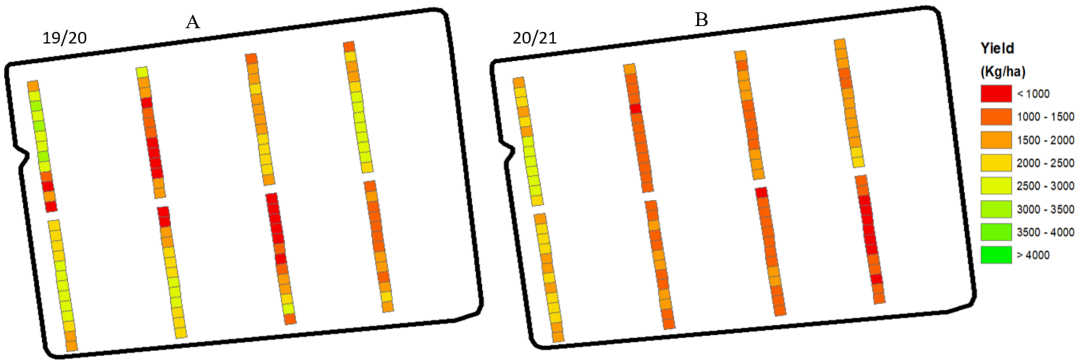


Figure 21: Yield maps derived from the combine test strips for the LFFI (A) and Control (B) fields, with results displayed for the 19/20 and 20/21 growing seasons, respectively.

In the Figure 22 the cumulative distribution function of a soybean yield demonstrates that the LFFI treatment presented for the 19/20 crop season values started from approximately 700 to 3430 Kg ha^{-1}, with 10% of the LFFI value being above the maximum of Control treatment. For the 20/21 crop this difference is greater, the values for the LFFI treatment ranged from approximately 1000 to 2800 kg ha^{-1}, with 12% of productivity above the maximum Control.

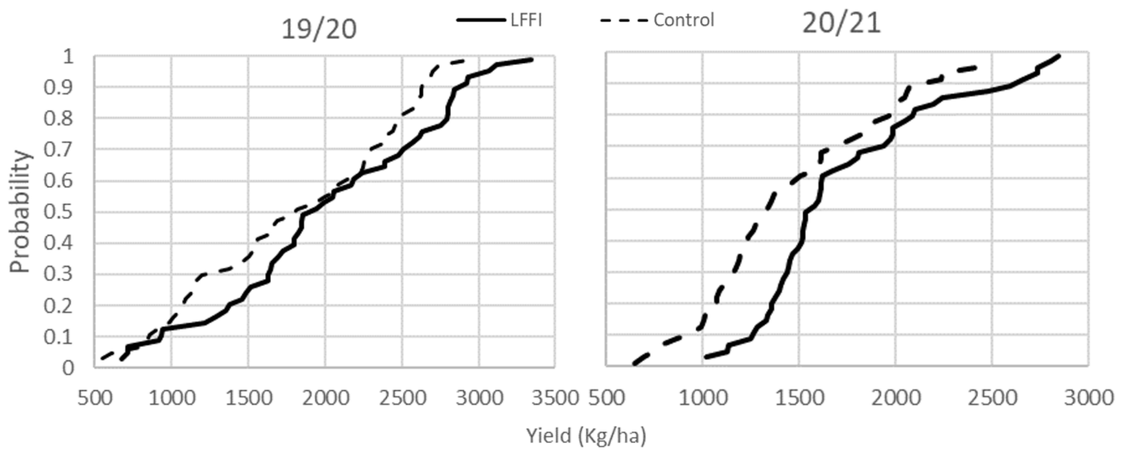


Figure 22: Cumulative distribution function of a soybean yield for LFFI and Control for the 19/20 (left) and 20/21 (right) grow seasons.

6.4 Discussion

We compared on-farm yield performance of a soybean with LFFI versus the traditional system (control), considering the effect of sodium on productivity, through the variability of electroconductivity.

6.4.1 LFFI project

The above LFFI design are similar to LFI project simulations reported by Bueno et al. (2020). The soil movement was 108 m3 ha-1, in a work carried out by Quiros et al. 2020 using land leveling with varied slope using GNSS-RTK System in areas with more slope (around 0.15%) found more similar values of soil movement and maximum cut, being around 120 m^3/ha and 0.12 m, respectively. Bueno et al. (2020) reported in a LFI model values of soil movement being around 146 m^3/ha as well as a 25% reduction in rice length and a 32% reduction in rice levee number. After LFFI system all depressions or locations with high altimetry was eliminate like reported by Bueno et al. (2020).

6.4.2 Effects of sodium in soybean yield

ECa30 presented a very strong correlation with sodium (*Na*) (Table 2), Corwin and Lesch (2005) related that the first application of ECa in agriculture was for the measurement of soil salinity and have been used to defne salinity spatial variability (HUANG et al., 2015). ECa30 values showed a strong correlation with *Na*, with coefficient correlation equal to 0.90, being similar with Corwin and Lesh (2005b) that found a correlation coefficient of 0.88 between ECa and *Na*. Salinity stress can considerably reduce grain filling duration, grain weight, grains per plant and consequently grain yield per plant in soybean cultivars. These reductions increase with increasing salinity (Ghassemi-Golezani et al., 2009). In addition to restricting plant growth, saline soils can restrict seed germination (CARLSON et al., 2013). Thus, this effect of *Na* on productivity was demonstrated by ECa30.

Correlation values between ECa30 and productivity showed a strong correlation in both treatments (Table 2). Soybean productivity decreases when the ECa30 increases, in a similar work developed by Kitchen et al. (2003) soybean yields also decreased with increasing ECa. Spatial soil variability mapping using electrical conductivity sensor is a very useful technology for precision farming (AMIN, 2004), the Veris ECa mapping has shown potential for establishing management zones on farms with significant soil variation (HUANG et al., 2015).

The results showed that ECa30 values above 70 mS m^{-1} began to show a reduction in crop yield, as seen in the regression tree (Figure 20). Soybean is considered a moderately tolerant plant and has an EC saturated paste threshold value of 50.0 mS m^{-1} (Maas, 1984). For moderately tolerant plants such as soybeans, each 10 mS m^{-1} increase above 50 mS m^{-1} results in a 20% yield loss (Feng et al. 2017). From the correlation between Yield, Eca and Na (Figure 18 and 19) and the regression tree, it is possible to trace a path to obtain high productivity (i.e ECa30 < 70 mS m-1 and LFFI treatment).

6.4.3 Crop produtivity between LFFI and Control

The yields were compared having the ECa30 as a covariate (Table 3), the means for the LFFI treatment in both seasons were significantly higher than the control. In a similar study carried out by Gupta et al. 2018 showed that the practice of soybean cultivation by furrow irrigated raised bed seed drill was found superior in comparison with conventional seed drill.

In the LFFI treatment a maximum value of 3430 kg ha^{-1} was obained (Figure 19), these values are very close when compared with the results obtained by Gubiani et al. (2018) (3.565 kg ha^{-1} in the 2014/15 growing season) and Fin et al. (2018) (over 4,000 kg ha^{-1} in the 2015/16 growing season), who also used raised seedbeds in lowlands. Gollo et al. (2021) obtained the maximum of 4,773.9 kg ha^{-1} with this technique, it was close to the maximum yield (4,618 kg ha^{-1}) obtained by Cassol et al. (2020), in raised seedbeds and furrow- irrigated lowlands. However, these experiments were harvested manually, which always presents higher averages yields than the combine harvester.

Dhakad et al. (2014) stated that ridges and furrows registered significantly higher plant population (44.8 and 46.2 m^{-2} at 2009 and 2010, respectively), plant height (67.4 and 69.4 cm at 2009 and 2010, respectively) than flat bed in soybean. The yield in recommended practice (ridge and furrow system) increased 30.18% over farmer practice (i.e. normal line sowing system).

The means for the Control treatment for both seasons were 1621 kg ha-1 (Table 3), this value was lower than the soybean production in the lowlands of Uruguay and Rio Grande do Sul, where only superficial drains are made, without alteration in the soil surface, tuat present an average of approximately 2400 kg ha^{-1} (DIEA, 2018; IRGA, 2019). In this same method (conventional) Goulart et al. (2021) found average soybean yield values of 2667 kg ha^{-1} and 752 kg ha^{-1} for the 14/15 and 15/16 harvests, respectively. In 2019, about 330,000 ha of soybean were grown in rotation with rice in the south of Brazil. However, the average yield was 2330 kg ha^{-1} (RIBEIRO et al., 2021). In the study period (2007–2015), the average grain yield of soybean for the 14 municipalities Rio Grande do Sul were 2200 kg ha^{-1} (THEISEN et al., 2017).

When we observe the yield potential that is possible to reach (Figure 19), for the 19/20 crop it was 2912 and 3430 kg ha^{-1} for the Control and LFFI, respectively, and for the 20/21 crop it was 2421 and 2856 kg ha^{-1}. That is, the LFFI system presented an average of approximately 500 kg ha^{-1} more than the control.

6.5 Conclusions

This was the first time an LFFI project was implemented in Uruguay for soybean production with furrow irrigation. This study shows that the incorporation of three novel technologies, global navigation satellite systems (GNSS) using real-time kinematic (RTK) correction and specialized topographic software, create new options for land leveling in three-dimensions. The LFFI design used here resulted in minimal soil disturbance while improving irrigation and drainage conditions and achieving more soybean yields as a traditional production system. For both years of the study the mean yields were below the the normal yield obtained by farmers, this is because *Na* demonstrated a negative impact on productivity. However, there were differences ($P<0.05$) in field-average grain yields between the LFI and Control treatments even though yield increases, and yield decreases were often associated with high ECa30 zones. The LFFI System in a zone with low *Na* concentration presented up to 35% more than the Control treatment.

7. Capitulo 3. Impacts of land forming on lowland soil properties and in rice yield

7.1 Introduction

Lowlands are predominantly flat and feature relatively shallow topsoil with high bulk densities (LIMA et al., 2009), low hydraulic conductivities, and impermeable subsurface soils. Thus, poor natural drainage is a key characteristic of this lowland agroecosystem (PARFITT et al., 2017) that has made it favorable for rice production for more than a century (THEISEN et al., 2017), however, the rotations with others crops have a positive impacts on resource use efficiencies, yields, and environmental indicators (PITTELKOW et al., 2016).

Before the introduction of others dry crops, some adjustments should be made in these areas, because the areas are inappropriate for this crops production in varying degrees (VERNETTI JUNIOR et al., 2009; BUENO et al., 2020). Dry crops, in order to present a better performance in lowlands in terms of drainage and irrigation, needs a correction of the micro relief, which, through land leveling, makes the soil surface ideal to obtain a better performance (BUENO et al., 2020).

Land Leveling (i.e., precision leveling or precision grading) has been practiced throughout the world for more than half a century (WHITNEY et al., 1950) and is considered a water conservation practice (BRYE et al., 2006). This practice is frequently applied to lowland areas predominantly used for flooded rice cultivation (AQUINO et al., 2015), improves water transport and distribution (ENCISO et al. 2018) and also enhances the efficiency of the other farm inputs (JAT et al., 2009).

However, caution must be used in applying the practice because leveling results in cuts exceeding 10-cm in shallow soils may cause problems (AQUINO et al., 2015), such as increased compaction, and changes in microbial community structure (BRYE et al., 2006) and impaired soil fertility (WALKER et al., 2003). Additionally, at current leveling costs of approximately USD 1 per cubic meter in southern Brazil, extensive soil movement makes leveling uneconomical (BUENO et al., 2020).

Levelling operations may also cause effects on the magnitude, variance and spatial variability of soil properties. Most studies have assessed the effects of levelling on soil properties using univariate statistical approaches by applying descriptive statistics, geostatistics, multiple linear regressions, etc. (BRYE et al., 2004, 2006; PARFITT et al., 2013, 2014; OGUNWOLE et al., 2014; SHARIFI et al., 2014).

A technological advancement called Land Leveling with Variable Slopes, also known as land-forming, combines global navigation satellite systems (GNSS) using real-time kinematic (RTK) correction and specialized topographic software (BUENO et al., 2020). Plani-altimetric surveys that use RTK systems provide high accuracy, especially along the z-axis (i.e., height) (RABELO et al., 2019; GARRIDO et al., 2019). In contrast to traditional laser land-leveling that produces a two-dimensional design having a single field slope, GNSS and machine control systems allow grade control to be achieved in three-dimensions. Thus, when RTK and GNSS technologies are used in conjunction with specialized software, designs with multiple slope directions and magnitudes can be generated within one field design.

One such land-forming option is Land-forming for Irrigation (LFI). LFI consists of smoothing the soil surface with automated land leveling equipment. This equipment can execute the software prescription that indicates the areas of the field that need to be cut or filled. All depressions and high points of the field are eliminated, allowing more uniform flow of water. This alternative method, explained by Bueno et al. (2020), may require smaller amounts of soil to be moved and, consequently, shallower cutting depths, than laser-leveling while still improving irrigation and drainage compared to 2-D laser leveling. It may also reduce soil disturbance associated with traditional levee-based leveling systems used in rice growing regions of Uruguay and South America.

Therefore, the aims of this study were to evaluate the impacts of land forming through evaluation of the magnitudes, variances and spatial distributions of selected soil physical properties of a lowland area in Uruguay; verification of the existence of a relationship between the magnitude of cuts and/or fills and the magnitudes of soil physical properties after the leveling process.

7.2 Materials and methods

7.2.1 Experimental area

Field experiments were conducted in a 5.5 -ha field located in Paso de la Laguna, Treinta y Tres department (Lat: −33.16S; Long: −54.10W) in eastern Uruguay (Figure 23). The field had been fallowed as grassland for eight years with rice being the last crop cultivated. The land-forming for irrigation (LFI) project was performed and the other half where no alteration of the native topography occurred. Mean annual rainfall at the site is 1360 ± 315 mm; annual total potential evapotranspiration is 1138 ± 177 mm; mean monthly temperature is 22.3 ± 0.9ºC (summer) and 11.5 ± 0.8ºC (winter). The Planosol, having a mapping unit of “La Charqueada” (MGAP, 1976), is typical of the lowland areas of Uruguay where rice rooting depth is limited by the presence of a claypan at approximately 20- to 30-cm.

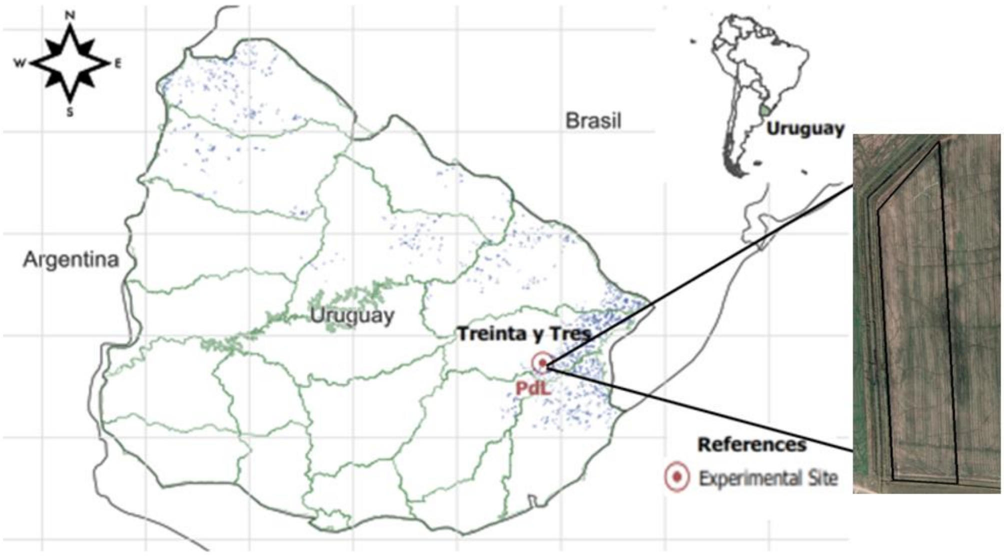


Figure 23: Rice cultivation regions in Uruguay. The inset shows the commercial-scale 5.5 ha field, located in Paso de la Laguna (PdL) of the Instituto Nacional de Investigación Agropecuaria (INIA), (Uruguay map courtesy of Federico Campos).

7.2.2 Digital Elevation Model and Land-forming for Irrigation (LFI) Project Design

A planimetric survey of the 12-ha field was conducted using a tractor equipped with a monitor and GNSS receiver antenna with RTK base station using methods described by Aziz et al. (2009). The resulting elevation data were processed using WM-Form version 1.3 software (TRIMBLE, SUNNYVALE, CA 94085) to generate a digital elevation model (DEM) of the field surface.

Calculations for the LFI design were performed using WM-Form software using a cut-to-fill ratio of 1.2 (GAMERO; BENEZ, 1989). This design was generated in the sub-design area mode which allows the user to choose the direction and minimum magnitude of a preset slope. Both cut and fill volumes are balanced in a way that depends on factors such as soil compaction. These calculations were performed using 3-m grids, a balanced-soil movement criterion, and a minimum slope of 0.05% (BUENO et al., 2020).

7.2.3 LFI Project Implementation

During the spring of 2019 the LFI design was uploaded onto a computer control system of a tractor (New Holland, TM 7020) equipped an earth-moving scraper (LOS ANTONIOS, 4 m of width). The scraper was equipped with control module and valves to automatically remove (cut) and deposit (fill) soil as per the design.

7.2.4 Classical statistics and analysis

Thematic maps were generated before and after leveling through the inverse of the squares of the distances . Therefore, a visual analysis of the spatial distribution of the properties was made. With the aim of determining which soil physical properties were most affected by the leveling process and to better describe future management practices to be carried out on leveled land, simple regression analysis was made using the Excel software based on the depth of cut and/or fill (CF) and the values of the soil physical properties after leveling.

7.2.5 Soil collection and analysis

Before and after levelling at each georeferenced point of the experimental grid, disturbed soil samples were collected in the 0– 0.20 m layer to determine the following soil physico-chemical properties. First, grid samples were collected prior to land leveling, with 16 points. The physical and chemical attributes evaluated were PH, organic carbon, phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sand, silt and clay.

7.3 Results and discussion

7.3.1 LFI field parameters

Figure 24 depicts how the LFI design was generated and implemented using the DEM of the 12-ha field site shown with 0.05-m contour lines (A), the WM-Fill LFI design project using 0.05-m contours (B) and corresponding cut-or-fill map used for the 5.5-ha LFI field (C). Five-centimeter contours are traditional rice flood depths used in the region and, thus, were used in the LFI field (left) and traditional rice levee leveling method that serve as the Control field (not shown).

The LFI project estimated that an average of 104 m^3 soil per ha, totaling 604 m^3 soil, would be moved on the 6-ha field. The average and maximum cutting depths were estimated to be 0.03-m and 0.16-m, respectively. By comparison, the WM-form software estimated an average of 284 m^3 soil per ha (i.e., 2.7-times more) with an average of 0.07-m and maximum cut depth of 0.38-m, would be required if a 2-D laser leveling design with a *uniform field slope* of 0.13% had been used. Moreover, if the traditional rice levee leveling method (i.e., no alteration of the native topography using 0.05-m contours) was used on LFI field, 3.6-km of rice levees would be required whereas using LFI, total rice levee length was reduced 14% to 3.1-km and levee number reduced 28% from 25 to 17.

The above LFI are similar to LFI project simulations reported by Bueno et al. (2020). However, these authors estimated higher levels of soil movement (i.e., 146 m^3 ha^{-1}) as well as a 25% reduction in rice length and a 32% reduction in rice levee number. In the actual field implementation of a land-forming with varied slope project using GNSS-RTK System in areas having a field slope of about 0.15%, Quiros et al. (2020) reported values more in agreement with the present study in terms of soil movement (120 m^3/ha) and maximum cut depth (0.12-m).

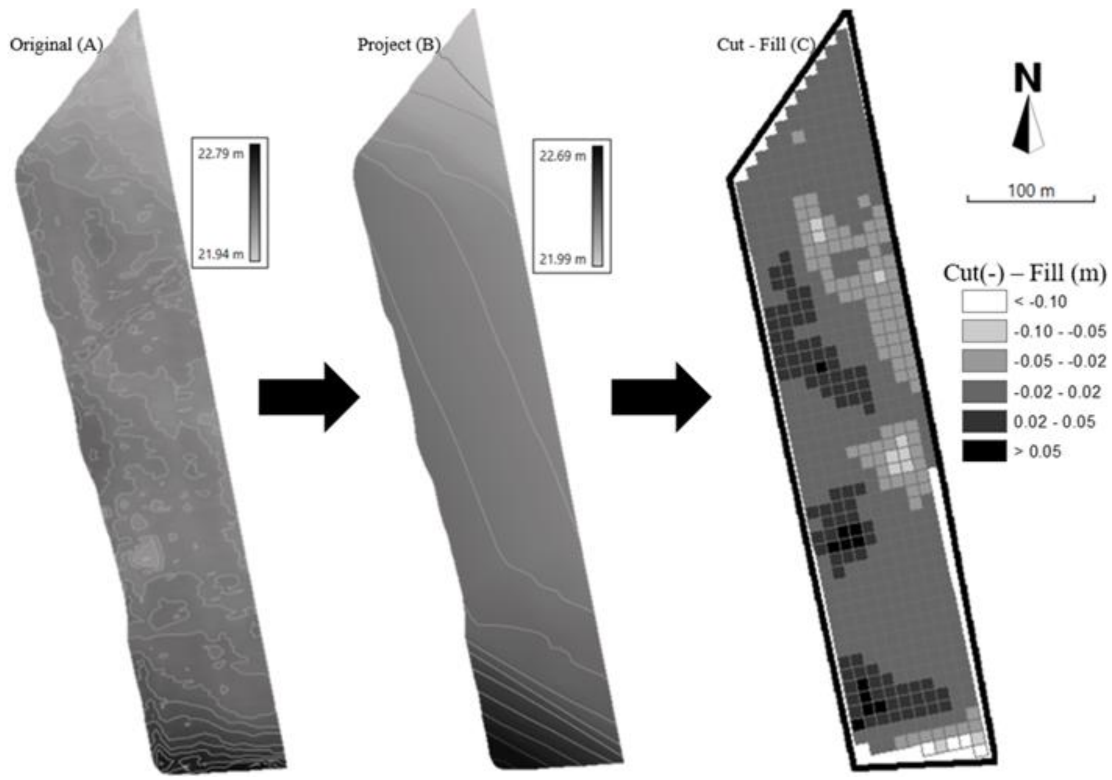


Figure 24: A digital elevation model (DEM) was created of the 5.5 - ha study field (A) and used to develop a land-forming for irrigation (LFI) project with levee contours set at 0.05-m (B) with the resulting cut-and-fill map implemented on a 5.5-ha portion of the field (C). The topography of 5.5-ha portion on the right side of the field was unaltered and served as the study control.

7.3.2 Impacts of land forming on the magnitudes and variances of soil properties

In table 8 average values for clay has a lower value before (24.31) than after (30.04) land forming, silt present a higher value before (49.72) than after (44.18) and the sand remained practically the same. Sand present almost the same value, being, before (25.96) and after (25.77).

Palmeira et al. (1999) and Bamberg et al. (2009), obtained lower values of clay and high of sand in lowland soil, in the 0– 0.20 m layer, managed with different rice cultivation systems. Parfitt et al. (2014) found before leveling (143 g kg^{-1} clay, 399 g kg^{-1} silt and 458 g kg^{-1} sand) and after leveling (154 g kg^{-1} clay, 375 g kg^{-1} silt and 471 g kg^{-1} sand) being an increase in average of 8% and 3% for clay and sand, respectively, and a reduction of 6% for silt.

The correlation between cut-fill with clay and sand was -0.49 and -0.21, respectively, being moderately negative for clay and weakly negative for sand. For silt it showed a moderate positive correlation of 0.41.

The mean organic carbon remained stable, but before LFI the minimum and maximum values were higher, presenting a higher variance, which indicates homogenization of C org after LFI. The correlation between cut-fill and OM was the highest found, being strongly positive with a value of 0.76.

Aquino et al. (2015) found that levelling decreased the mean values of silt and Corg in cut zones. Several studies pointed out that the most significant changes due to land leveling are related to the organic matter (OM), OM decrease because the mixing of the soil horizons usually accelerates the deterioration of their organic compounds (RAMOS, 2017; MARZOLFF; PANI, 2018).

Castro et al. (2015) established OM can affect the key soil physical, chemical, and biological properties. Land leveling resulted in 20% average decrease in OM in the 0–0.20 m layer (PARFITT et al., 2013), which can represent a substantial loss of potential native soil fertility for crop production (RAMOS; MARTÍNEZ-CASASNOVAS, 2006). Despite that OM varies over the space and time, it is useful for the understanding of many climatic, ecological, hydrological, and nutrient-based processes that operate in different intensities and spatio-temporal scales throughout landscapes (NIELSEN; WENDROTH, 2003).

The Na values were for the mean of 0.94 and 0.55 (meq $100g^{-1}$) and for the variance of 0.14 and 0.08 (meq $100g^{-1}$), before and after the LFI, respectively. Parfitt et al. 2013 also found a decrease, but only 4% on average, with a variance of 35%.

The average of PH went from 5.56 to 5.90 (%), the intense soil disturbance and transport during the leveling operation decreased the average values of in 42% after LFI, however Parfitt et al. (2013) and Walker et al. (2003) reported that the PH remained stable even after leveling. Abreu Jr et al., 2003 reported that practically all soil attributes described above are influenced by pH. The pH is positively correlated with the values of P, Ca, Mg, K and cation exchange capability (CEC) and negatively with the saturation of Al. Results by Öztekin et al. (2013) show that significant values in PH increases due to land leveling for both surface and subsurface soils.

The average of Ca before was 5.33, rising to 5.58 (meq 100g-1), Parfitt et al. (2013) reported a reduction of 18% after leveling. The K means remained stable, showing no variation as a function of the LFI. Brye et al. (2004) evaluated the impact of levelling on the magnitude of soil chemical properties and also found that the levelling operation increased the potassium (K) content in the 0–0.10 m soil layer. The authors attributed this behaviour to the presence of certain clay minerals such as illite, particularly the presence of a clay horizon in the deeper soil layers. Castilhos and Meurer (2002) found micas in the clay fraction of the argillic horizon of a similar Albaqualf soil in the same region where the present study was carried out, a fact that may be related to the increase of the average value of potassium after levelling.

The average productivity was 12450 kg ha-1, above the annual average for the country, which is 8390 kg ha-1 (DIEA, 2018) with values ranging from 8470 to 15260 kg ha-1. The correlation coefficient presented a value of 0.63, being strongly positive.

It is observed that the mean and median values of most of the chemical attributes studied are close. According to Little and Hills (1978), when the mean and median values are close, the data tend to have a normal distribution.

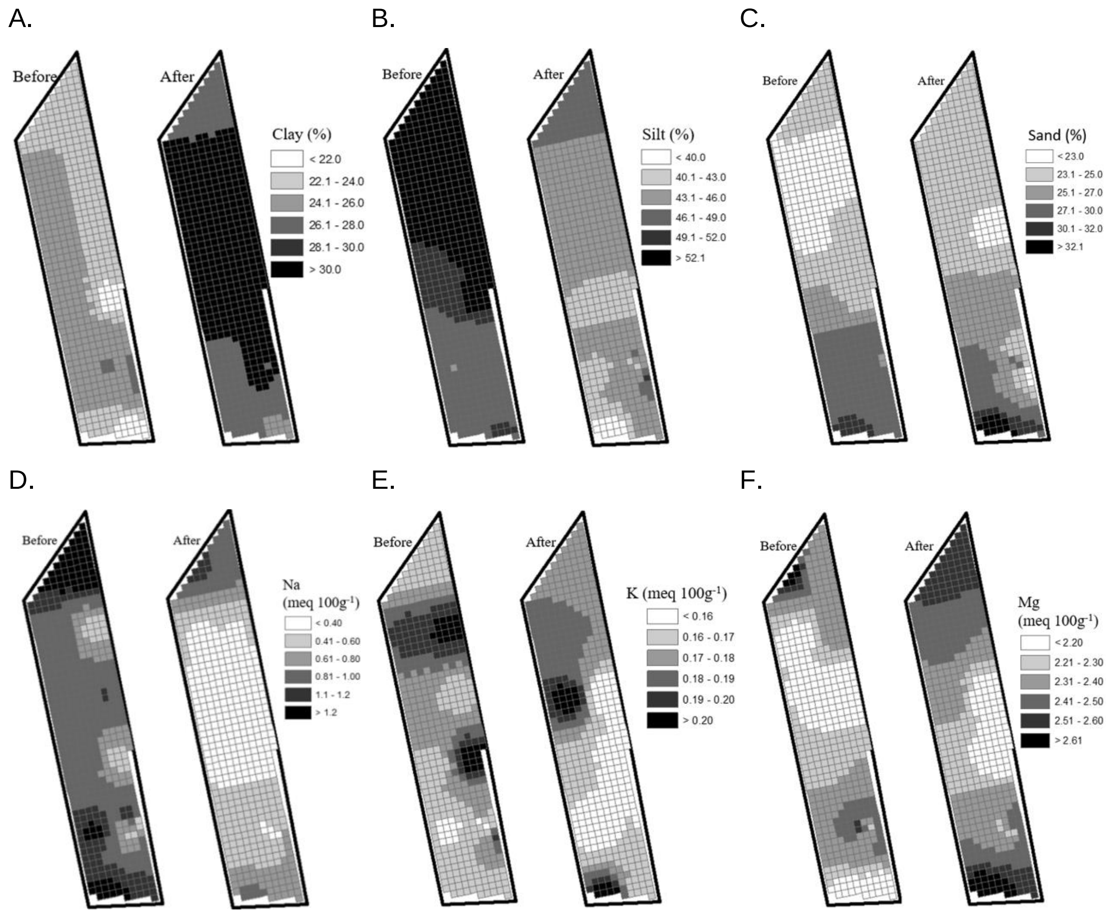
Table 8: Statistics for soil properties measured before and after land forming (LFI). Pearson's values are related to the correlation between mean diference of soil property and cut-fill.

Property	Mean	Median	Minimum	Maximum	Variance	P pearson
Clay (%)[1]	24.31	23.37	20.14	28.45	7.94	-0.49
Clay (%)[2]	30.04	31.59	24.28	32.58	6.16	
Silt (%)[1]	49.72	49.21	42.62	57.26	19.17	0.41
Silt (%)[2]	44.18	44.75	35.07	52.64	14.21	
Sand(%)[1]	25.96	25.27	20.06	31.03	12.18	-0.21
Sand(%)[2]	25.77	24.24	18.95	37.02	19.12	
C org (%)[1]	1.40	1.39	1.06	2.32	0.09	0.76
C org (%)[2]	1.42	1.43	0.93	1.94	0.06	
Na (meq $100g^{-1}$)[1]	0.94	0.93	0.43	1.51	0.14	-0.24
Na (meq $100g^{-1}$)[2]	0.55	0.44	0.20	1.20	0.08	
PH (%)[1]	5.56	5.63	5.21	6.08	0.05	-0.41
PH (%)[2]	5.90	5.79	5.56	6.81	0.10	
Ca (meq $100g^{-1}$)[1]	5.33	5.40	3.99	6.47	0.53	0.08
Ca (meq $100g^{-1}$)[2]	5.58	5.40	4.90	6.57	0.28	
K (meq $100g^{-1}$)[1]	0.17	0.17	0.14	0.22	0.00	0.61
K (meq $100g^{-1}$)[2]	0.17	0.17	0.14	0.22	0.00	
Mg (meq $100g^{-1}$)[1]	2.29	2.30	1.92	2.72	0.05	0.03
Mg (meq $100g^{-1}$)[2]	2.42	2.50	2.02	2.87	0.05	
P (meq $100g^{-1}$)[1]	6.59	5.78	3.48	19.16	12.98	0.23
P (meq $100g^{-1}$)[2]	7.44	7.20	5.35	11.38	3.33	
Yield (kg ha^{-1})	12450		8470	15260	1007.00	0.63

7.3.3 Spatial distributions of selected soil physical properties before and after LFI.

Maps of soil properties before and after leveling are presented in figure 25. Before LFI, clay presented a uniform spatial distribution with a gradual increase from east to west, Silt a gradual increase from south to north and sand presented opposing behavior, after LFI clay had an increase with the greatest concentration in the central part.

Organic matter and K showed an increase and decrease in value in the eastern part and an increase in the western part of the area, following the same pattern of the cut and fill map (Figure 24C).



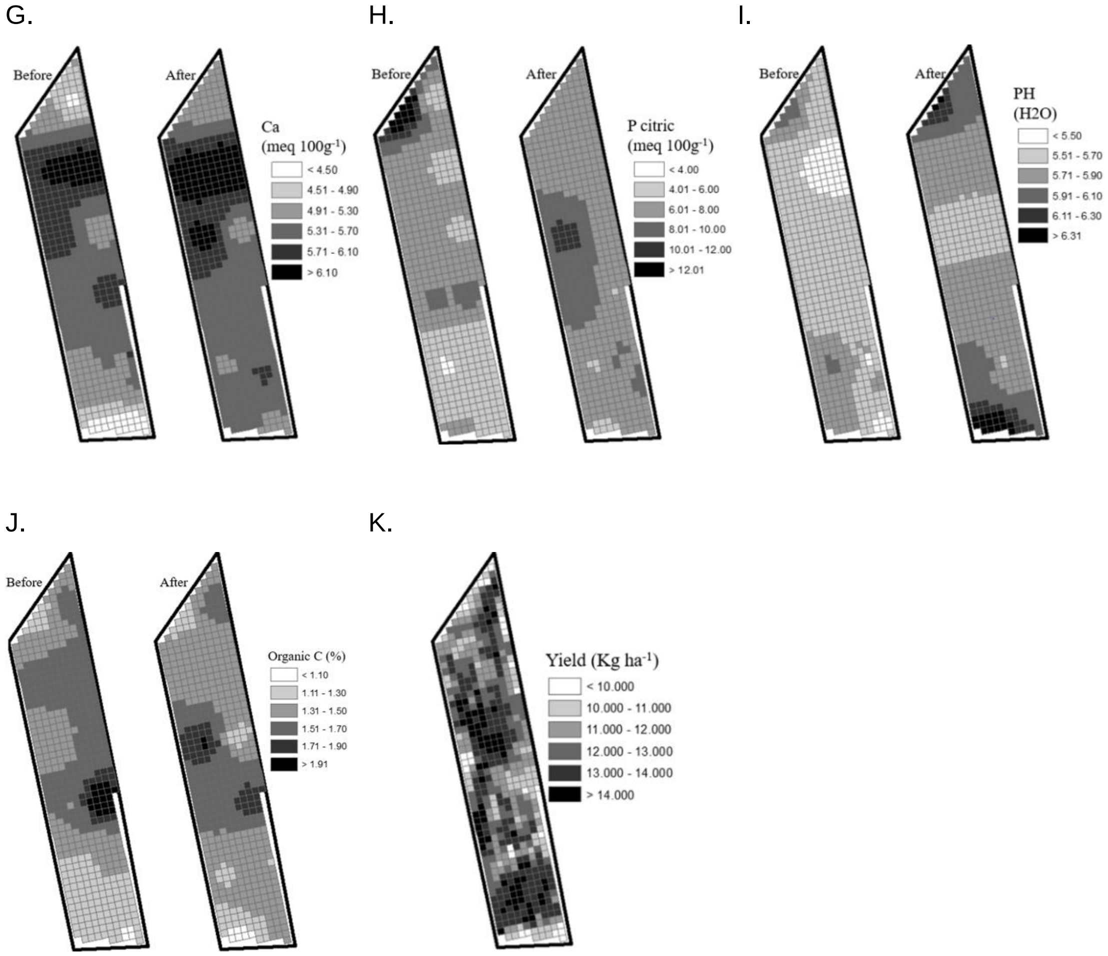


Figure 25: Maps of the spatial distribution of concentrations of clay, silt, sand, pH (H2O), soil organic matter (SOM), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and phosphorus (P) before and after LFI.

7.3.4 Relationships between the magnitude of cuts and/or fills and soil physical properties

In order to better understand the relation between magnitudes of cuts and/or fills resulting from leveling and the soil properties, mathematical relationships between them were established (Figure 26). Although no defined relationship among soil property values and the magnitudes of cuts and fills, which is confirmed by the low R^2 coefficients, most of the relationships between properties are statistically significant. The effects of land leveling on the soil properties evaluated occurred mainly over the whole area, and not specifically in the cut or fill areas, this is due the low values of the slopes of the regressions in relation to the respective intercepts.

The relation was positive quadratic for Clay and sand, indicating increase of these attributes in cut areas and stability in fill areas. For Silt it was negative quadratic indicating decrease of these attribute in cut areas and stability in fill áreas. Parfitt et al. (2014) found similar results, with the values increase for Clay and sand, and decrease for silt. Silt and K presented an R^2 around 0.40, whereas for clay the R^2 is 0.48. found a similar behavior for silt, with values increasing in fill zones, but with a much lower R^2.

Carbon organic (Org C) has the highest value of R^2 (0.58), indicating that there was an increase in the fill zones and a reduction in the cut zones. Soil organic matter is an indicator of soil quality and affects soil physical, chemical and biological properties, and levelling causes a decrease of soil organic matter, altering the topsoil quality negatively (CASTRO et al., 2015). Similar results were reported by Brye (2006) in a soil classified as Sharkey clay used for irrigated soybean and rice production in the Mississippi Delta region of northeast Arkansas, USA, where the contents of Org C and P decreased and the contents of K increased as a result of the leveling operation.

Mg and P citric present values of R^2 very lower, indicating an increase in the fill zones and a reduction in the cut zones, Parfitt et al. (2014) found that values of Ca, Mg, P, and SOM decreased in the soil profile. However, Brye, (2006) found the means of Ca contents changed in opposite directions as those observed in the present study. Walker et al. (2003) reported only small differences were seen in Mg and K concentrations.

The PH and Na values indicating that there was a reduction in the fill zones and an increase in the cut zones, this same relationship of PH and Na was found by Parfitt et al. (2013), who also obtained low R^2 values for these components. Bitencourt et al. (2016) noted that levelling caused a tendency to that had a decrease in PH and a increase in silt, K, Org C em P. Fill areas have higher fertility, especially in terms of P and K contents, which directly reflects on the productivity of irrigated rice (WINKLER, 2018).

When the combine harvest of whole field results (Figure 26K) were overlayed with the corresponding LFI cut-or-fill map values (Figure 26L), the complete variability in rice yield is capture, ranging from the highest cut (-0.16 m) to the highest fill (+0.05 m) (Figures 26K). A larger impact on yield effects can be observed at this level with reduction up to 30%, a significant relationship between soil alteration and yield deviation was observed (Table 1).

Similar results were found by Winkler (2018) and Muñoz (2019) in areas where land leveling with uniform slope was performed using the laser system. Both authors demonstrated that soil cuts deeper than 0.05-m reduced rice yields while cuts reaching 0.3-m reduced rice yields by up to 20% below the average.
Analysis of variance indicated that rice yield in five of the seven fields was lower in the cut areas than in the fill areas (WALKER et al., 2003). He also reported that yield declines in cut areas were strongly related to the amount of soil moved during land leveling, although they were unable to show if this was due to reduced nutrient availability.

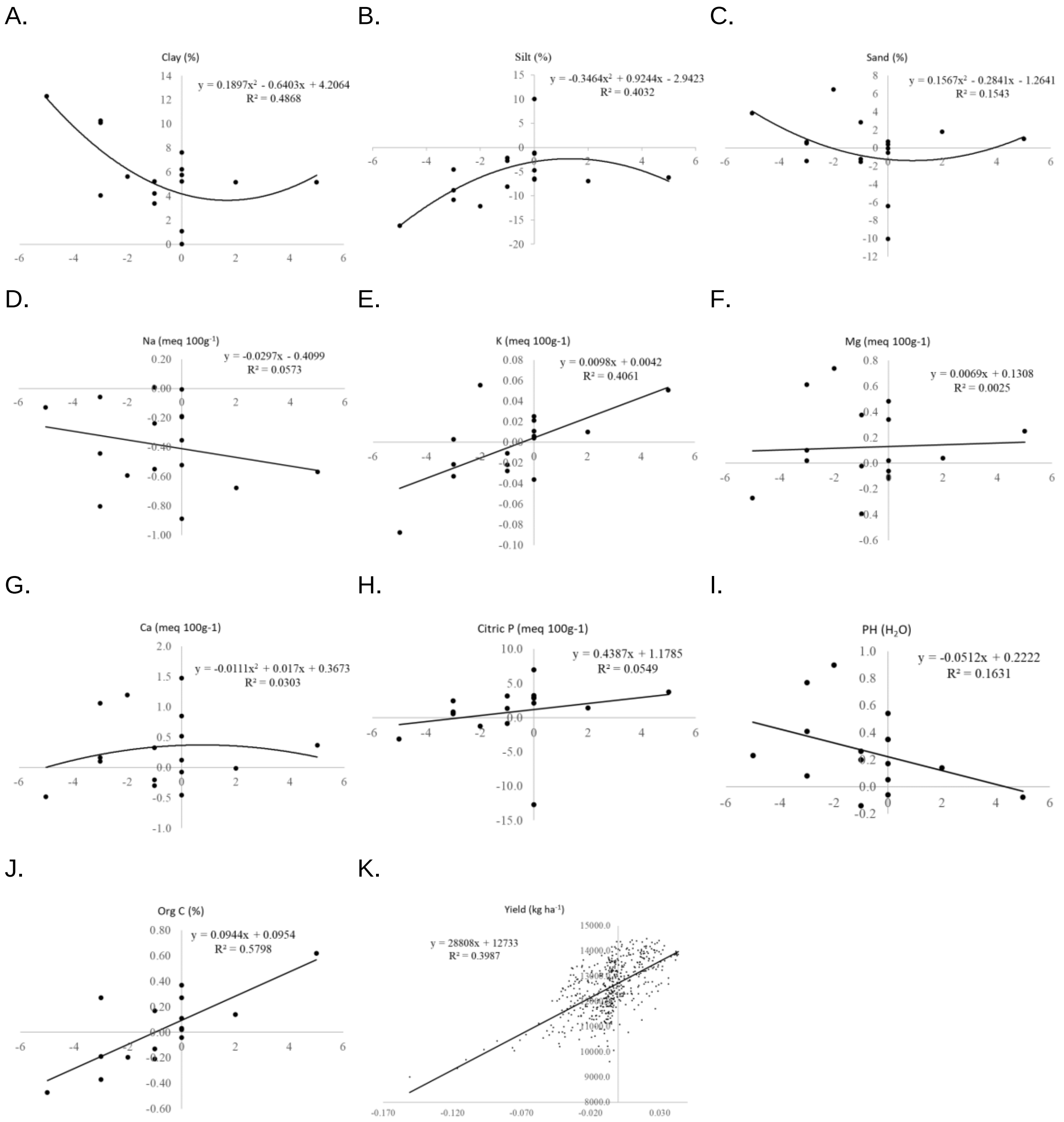


Figure 26: Regressions between cut (-) and fill (+) depths and pH (H2O), SMP index, soil organic matter (SOM), calcium (Ca),magnesium (Mg), aluminum (Al), manganese (Mn), potassium (K), sodium (Na), potential acidity (H+Al), cation exchange capacity (CEC), and phosphorus (P), as well as equations and respective coefficients of determination. Ns Nonsignificant. * and **Significant by the t test at 5 and 1% probability, respectively.

7.4 Conclusions

1. The agricultural effects from land forming in this cut range was not very aggressive to the soil properties, as the bibliography demonstrates.

2. The property presented the most changes and correlation with cut-fill was OM, since it decreased the minimum and maximum values, although the mean remained the same.

3. The effect of leveling on all soil physical properties occurred over the whole area and not specifically in the cut or fill areas.

8. Considerações finais

A aplicação do modelo de sistematização com declividade variada visando irrigação (DVI) mostrou que não houve uma queda de rendimento significativa de rendimento para o arroz, sem alteração expressiva nas propriedades químicas e físicas do solo, isso se deve ao fato do corte médio não ultrapassar os 0.05 m. Já para a soja, considerando a influência do sódio (Na), o sistema sulco-camalhão propiciou um aumento de produtividade, podendo atingir altos patamares.

Sendo assim, a adequação da superfície do solo é fundamental para que com a utilização do sistema GNSS combinado com as tecnologias embarcadas em máquinas agrícolas e sistemas SIG possam tornar este ambiente produtivo mais apto para realizar a automação dos processos de irrigação e também para a utilização de métodos alternativos de manejo de água que sejam mais econômicos.

Portanto, estudos que contemplem estas áreas do conhecimento devem seguir sendo realizados para que cada vez mais o manejo da água seja mais eficiente e sustentável.

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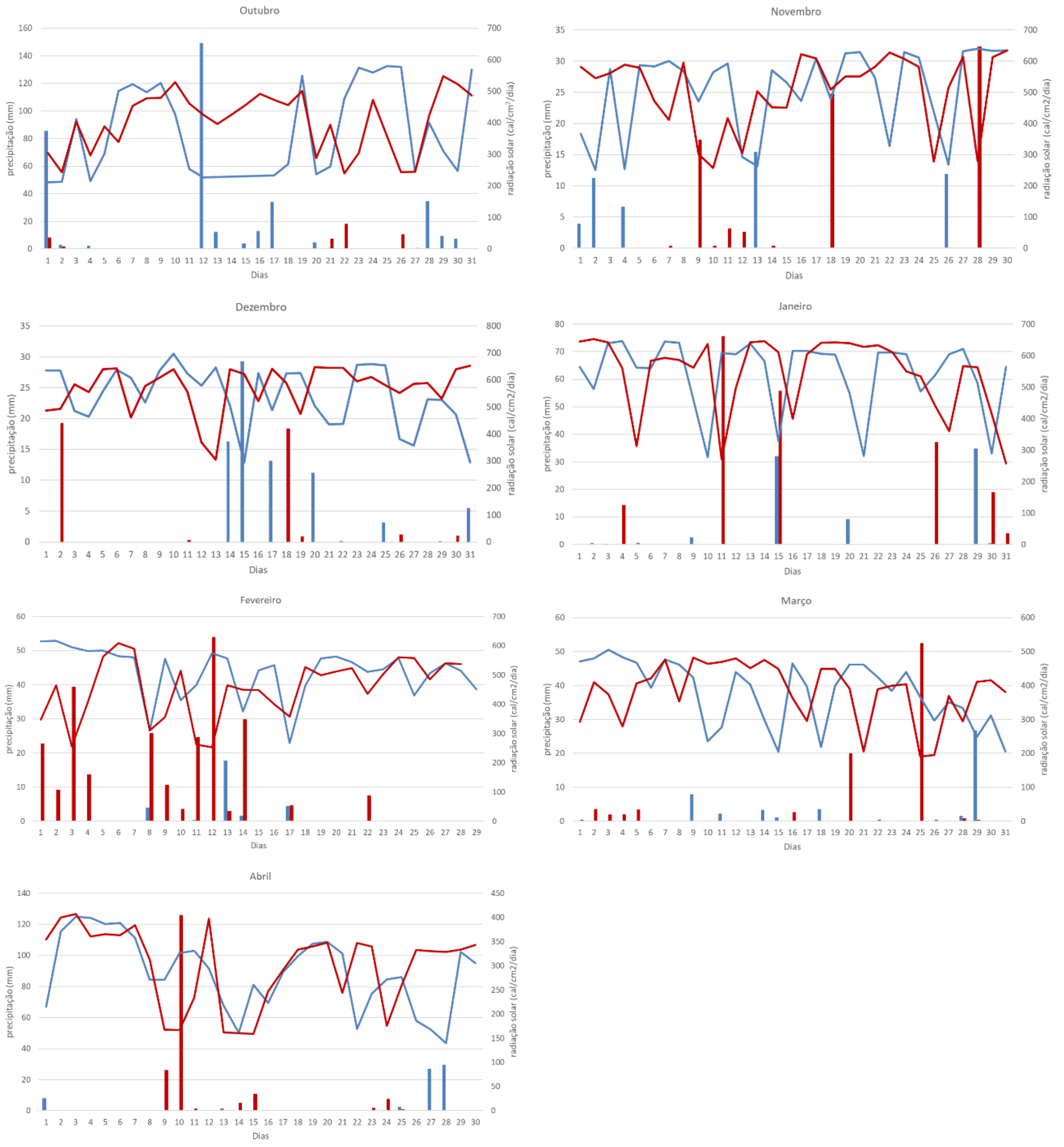
Apêndice

Apêndice 1 – Dados de precipitação (colunas) e radiação solar (linhas) para o período das safras 2019/2020 (vermelho) e 2020/2021(azul).



Apêndice 2 - A caracterização química e física do solo da área cultivada com arroz.

Ponto	pH* (H2O)	C.Org %	P* µg P/g	Ca* meq/100g	Mg* meq/100g	K* meq/100g	Na* meq/100g	Textura (Familia Textural)* % Areia	% Silte	% Argila
1	5.9	0.89	3.5	4.2	2.0	0.15	1.33	41	38	20
2	5.5	1.30	10.5	4.5	1.8	0.16	0.39	**	**	**
3	5.5	1.50	8.6	5.3	2.3	0.18	0.99	26	46	28
4	5.4	1.46	8.8	5.1	2.1	0.18	0.31	31	45	24
5	5.5	1.30	13.6	6.3	2.4	0.26	1.00	23	48	28
6	5.4	1.67	12.3	5.8	2.4	0.25	0.58	16	55	28
7	5.9	1.30	7.4	5.1	2.9	0.19	1.84	18	53	28
8	6.3	1.00	6.7	6.7	3.0	0.19	0.54	20	52	29
9	6.0	1.08	8.1	5.5	2.6	0.29	0.84	28	44	28
10	5.6	1.33	4.8	6.0	2.5	0.17	0.52	27	47	26
11	5.6	1.53	8.5	4.9	2.0	0.16	1.07	25	49	26
12	5.5	1.51	12.1	5.1	1.9	0.16	0.87	28	46	26
13	5.6	1.23	4.3	5.5	2.3	0.16	1.16	20	51	28
14	5.4	1.06	5.9	4.0	2.0	0.16	1.14	30	50	20
15	5.2	1.46	4.3	4.6	2.1	0.14	0.86	31	47	22
16	5.6	2.32	9.0	5.9	2.3	0.22	0.43	23	57	20
17	5.5	1.58	5.6	5.0	1.9	0.16	1.01	24	54	22
18	5.3	1.60	5.0	6.5	2.4	0.21	0.43	22	55	22
19	5.6	1.57	4.4	4.4	2.3	0.16	1.51	23	55	22
20	6.1	1.08	19.2	5.0	2.7	0.16	1.39	25	53	22
21	5.5	1.56	6.3	6.2	2.1	0.20	0.88	20	54	26
22	5.7	1.32	7.7	5.9	2.2	0.17	0.92	22	52	26
23	5.6	1.49	8.5	5.6	2.2	0.16	1.00	25	49	26
24	6.0	1.11	3.5	5.2	2.4	0.15	1.46	30	43	26
25	5.9	1.13	6.6	4.2	2.1	0.17	1.49	31	47	22
26	5.7	1.46	6.2	5.9	2.5	0.17	0.48	25	46	28
27	5.8	1.34	4.4	5.7	2.5	0.18	1.24	30	44	26
28	5.8	1.30	5.2	5.6	2.6	0.17	0.57	27	45	28
29	5.9	1.17	4.2	5.9	2.6	0.21	0.93	29	43	28
30	5.7	1.18	3.9	4.8	2.3	0.17	0.50	29	47	24

Apêndice 3 - A caracterização química e física do solo da área cultivada com soja.

Ponto	pH* (H2O)	C.Org %	P* µg P/g	Ca* meq/100g	Mg* meq/100g	K* meq/100g	Na* meq/100g	Textura (Familia Textural)* % Areia	% Silte	% Argila
1	5.3	1.50	7.4	6.8	2.3	0.17	0.83	16	56	29
2	6.0	1.35	8.2	3.6	2.3	0.14	1.81	13	60	27
3	5.7	1.43	10.8	3.7	2.1	0.14	1.37	21	56	23
4	5.7	1.25	10.1	6.0	2.8	0.24	1.29	11	58	31
5	5.2	2.55	21.5	6.3	2.6	0.33	0.84	17	52	31
6	5.8	0.91	4.2	3.9	2.1	0.14	1.62	19	57	24
7	5.6	1.08	5.4	3.7	2.1	0.16	1.09	24	54	22
8	5.4	2.00	8.9	7.2	2.4	0.23	0.90	16	55	29
9	5.5	1.59	5.2	7.2	2.7	0.20	0.53	16	51	33
10	6.4	1.05	2.7	3.8	2.3	0.11	1.68	22	51	26
11	6.0	1.24	4.0	5.8	3.0	0.16	1.49	19	49	33
12	5.3	1.80	6.9	5.7	2.7	0.19	0.67	16	51	33
13	5.4	1.44	4.6	4.8	2.3	0.16	0.81	16	51	33
14	5.7	1.30	4.3	4.8	2.3	0.13	1.17	**	**	**
15	6.3	0.99	2.7	4.2	2.5	0.12	1.88	23	46	31
16	5.4	2.02	15.9	6.4	2.5	0.22	0.66	14	51	35
17	5.3	1.48	14.8	6.0	2.1	0.19	0.53	17	50	33
18	5.4	1.53	7.1	5.8	2.4	0.17	0.56	17	50	33
19	5.6	1.08	4.4	4.1	2.2	0.12	1.13	24	49	27
20	5.3	1.53	8.5	5.7	2.2	0.14	0.73	18	47	35
21	5.3	1.67	6.3	6.1	2.3	0.18	0.54	14	53	33
22	5.3	2.81	9.7	6.8	2.8	0.19	0.75	14	45	41
23	5.3	1.97	7.5	6.7	2.2	0.17	0.69	15	52	33
24	5.3	1.68	13.1	6.5	2.4	0.23	0.64	13	58	29
25	5.5	1.85	9.7	7.5	2.3	0.22	0.96	17	52	31
26	5.4	1.10	8.5	7.2	2.4	0.19	0.97	15	55	31
27	6.7	1.73	7.9	4.1	2.8	0.26	2.65	23	55	22
28	6.8	1.00	11.0	4.3	2.8	0.24	2.57	25	53	22
29	5.7	1.79	6.9	7.6	2.4	0.16	1.09	15	55	31
30	5.6	2.00	10.6	7.1	2.4	0.19	0.82	15	55	31

Apêndice 4 – Irrigação no arroz para as safras 19/20 e 20/21 nas áreas sistematizadas e sem sistematizar.