BioLogic AgFood
from paddock to plate for health

The Soilkee Renovator Project

an Independent Study
by Dr Maarten Stapper

Results at-a-glance

- Harvest results show a persistent advantage of Soilkee compared to Control and Fertilizer treatments in feed quality. For example, crude protein increased by 20% (4.2% protein) in May 2013, 13% (2.3% protein) in August and 20% (2.4% protein) in May 2014, digestibility by 5, 3 and 8%, and metabolisable energy by 6, 4 and 10%, respectively.
- Drymatter production in August 2013 improved by 30% while fresh weight increased by 46% and its crude protein content by 45%; preferential grazing influenced later harvests.
- The average percentage soil organic carbon in the topsoil under Soilkee treatments increased by 0.9%, a 23% increase in one year. The associated significant decrease in bulk density and increase in porosity allow more roots to penetrate deeper. Soilkee Renovator is an excellent tillage implement for soil regeneration in Carbon Farming.
- Final soil tests show an average change in improvement of 57 soil chemistry factors for Soilkee treatments to be some 13% better than Control and 18% better than Fertilizer. For example, CEC of Soilkee treatments was improved by 21% compared to Control.
- Nutrients from the total extractable pool are significantly made more plant-available. For example, improvements of 34, 51 and 122% in plant available Phosphorus, Sulphur and Nitrogen, respectively, obtained as average for Soilkee treatments.
- The Soilkee operation improves soil health and plant growth over the whole paddock rather than in strips along the ‘kee’s, with continuing improvements during the whole year. Soilkee activates the soil biology which enhances root growth. This, supported by carbon sequestration, loosens the soil not only along the ‘kee’s but also in the undisturbed soil between them.
- Many measured soil and feed quality traits for the Soilkee-only operation in this study were as good as applying seed and fertilizer with Soilkee. Preferential grazing and dry conditions during summer affected seedling survival in Soilkee and seed treatments. The Soilkee operation by itself can be a dominant factor, thus reducing any operational risks for Soilkee and seed.

Photo 1. The Soilkee Renovator operation

Introduction

Soilkee Pty Ltd located near Drouin in West Gippsland received from Commercialisation Australia a “Proof of Concept” grant to conduct an independent field trial for the Soilkee Renovator tillage machine. The aim of this trial was to quantify the impact of the Soilkee Renovator operations (Photo 1) on pasture productivity and soil health. The project was conducted from April 2013 till May 2014 on three farms in the Gippsland region. Medium to high production farms with capable managers were selected as the individual farmer’s own management and learning style was important in facilitation of the trial. With the current lack of operational Soilkee knowledge, and in order to build that knowledge base, such farmers are the first target group for using the Soilkee Renovator.

The trials were conducted in three paddocks on each of three farms and all paddocks were grazed between the successive trial harvests as part of the commercial farm rotations. Preferential grazing was noted on the Soilkee treatments and affected outcomes as the project progressed, especially fodder weights per hectare and pasture composition.

This report describes the Soilkee Renovator operational procedures and the trials results of harvests with feed quality, soil tests and field observations.

Soilkee Operation

The Soilkee Renovator was developed to renovate pastures with a minimum loss of grazing days. Its working width is 3m over which it makes 7 slots or ‘kee’s into the soil (Photo 1) by power-take-off driven chisels. The ‘kee’s formed were 5cm wide and 8cm deep using the standard setting. As shown on the photo some soil is deposited in the process on the surface between ‘kee’s, thus leaving a groove in the ‘kee’. The soil in the ‘kee’s is of fine tilth through the active mixing of soil. The soil between the ‘kee’s under the deposit is left undisturbed. The deposit thickness depends on machine settings such as working depth. The working rate is between 1 and 1.5 hours per hectare and becomes faster for successive operations as the soil improves. Observations during development pointed to activation of earthworms and microbes in ‘kee’s and under the soil deposits as drivers for the rapid process of soil regeneration.

A diverse seed mix is applied from the seed box during the operation and may include ryegrass, oats, clover, peas, chicory, plantain and, at appropriate times, maize and millet. Seeds drop in seven rows and land in the ‘kee’s between the surface and 4cm depth. Experiences leading up to the Project trials showed a remarkable success rate of the Soilkee and seed operations (Photo 2) under variable conditions from dry and hot to wet and cold. The photo on the right shows a successful summer crop established in a pasture to bridge the autumn feed gap.

No grazing days are lost when sowing into an established pasture with the Soilkee operation. It obviates the need for pasture “spray out”, mulching, aeration and sod seeding, and comes with reduced need for brought-in feed and fertilizer applications. The diversity of pasture species leads to a healthier herd and better output. Successive single-pass operations, squared or angled on the previous to improve soil from four directions, will quickly regenerate soils and lead to higher productivity and more cows per hectare.

Photo 2. Growing plants from seeds dropped onto the ‘kee’s of Soilkee Renovator

Three farms were selected with three paddocks each to generate enough numbers for proof of concept. They all had brownish loam topsoils on different subsoils. The farms were:

- Farm A – organic beef farm in the Warragul district of West Gippsland with some red subsoils. Mean annual rainfall of 1020mm.
- Farm B – organic dairy farm in Central Gippsland with sandy loam subsoils. Mean annual rainfall of 700mm.
- Farm C – dairy farm in the Drouin district of West Gippsland with red and heavy clay subsoils. Mean annual rainfall of 1094mm.

Seeds and fertilizers were included as treatments in the trial. The seed mixtures and rates were based on successful outcomes of evaluations on the home property (see above). It was decided to broadcast granulated mineral fertilizers as these allow greater biological activity in the soil foodweb than the standard water-soluble fertilizers which are too salty or acid and can be easily lost by becoming unavailable when locking-up in soil (such as Phosphorus), leaching into ground water or volatilizing into air. Such mineral fertilizers applied have to be solubilised by microbes when needed. The mineral fertilizer composition and rates were derived from soil samples done in April 2013. 'Fertilizer' mentioned here after refers to these mineral fertilizers.

Large treatment strips of about one acre were used of multiple 3m machine working widths without replication. The treatments were parallel strips of 200 to 300m long and were plotted with GPS, which was used for the Soilkee and harvest operations. The Soilkee trials were usually situated in the middle of a paddock with the Control and full Fertilizer treatments reaching to either fence. Each paddock trial was divided into six segments to represent, in the order of layout, the following treatments:

1. Control
2. Soilkee
3. Soilkee and seed
4. Soilkee and seed on half rate fertilizer
5. Soilkee and seed on full rate fertilizer
6. Fertilizer full rate

The **1st Soilkee operation** between 22 and 24 April 2013 was the start of the trials. Soils were only moist on the surface and relatively dry underneath. Rainfall during the next five weeks was 52 to 100mm and in Soilkee treatments pasture growth recovered and seeds emerged. At the first harvest on 30-31 May 2013 the seed status in the 'kee's was mostly patchy for oats, some ryegrass, some peas and few small seeds. During August-September more of the small seeds did emerge, with staggered emergence a recurring experience with Soilkee.

The **2nd Soilkee operation** on 22-24 November was done to evaluate the introduction of summer crops maize and millet in the seed mix to allow for a possible continuous feed supply during the lean months of autumn. The 2nd operation used the same GPS guided track positions as the 1st, thus again mixing soil and uprooting plants in the 'kee's. The second mixing of soil in the 'kee' is not as effective as making new 'kee's with recommended successive angled operations. Conditions were wet and muddy after 50-62mm rainfall in the preceding fortnight. Survival of seedlings was poor due to preferential grazing and hot, dry weather.

Feed Production and Quality

Feed production and quality for the treatments in the nine paddock trials were measured at periodic harvests with grazing events or silage cuts in between. Production was not measured prior to grazing or with silage cuts. Because preferential grazing on the Soilkee treatments was observed, the measured production across treatments after August does not reflect true production differences between treatments. On 31 May 2013 the first pasture samples were taken manually in one paddock on each farm for Control and two Soilkee treatments to evaluate the early impact of the Soilkee operation on fodder quality. Machine harvests were done for all treatments on 3 paddocks again in August 2013 (not yet affected by preferential grazing), 8

paddocks in January 2014 and 7 paddocks in May 2014. Samples for the feed tests were taken randomly with manual cuts or sub-sampled from mower bin. All feed tests on fresh fodder samples were done by Agrifood Technology Laboratory in Werribee, Victoria.

May 2013. The first pasture quality comparison between Soilkee and Control treatments was done around 31 May, some 40 days after the 1st Soilkee operation. Soilkee treatments provided an 18 to 22 % increase in the drymatter crude protein compared to Control which was an average improvement of crude protein in fresh weight of 23%. Drymatter digestibility and metabolisable energy for Soilkee were 5 and 6%, respectively, better than Control.

These results represent averages of the **in** and **between 'kee'** samples taken in the Soilkee treatments. This separate sampling was done to quantify pasture quality for plant growth activated by the 'kee's or by the soil deposit between the 'kee's. Results showed no difference in pasture quality in or between the 'kee's. The coefficient of variation (CV) of the means across paddocks for the quality traits measured was between 3 and 12%. Therefore, quality differences for in and between 'kee's can be discarded, unless nutritious crops in the 'kee' become dominant.

The lack of differences in feed quality of pasture within and between 'kee's could be associated with the below average establishment of seeds sown in the 'kee's. However, observations were that during the first grazing after Soilkee+Seed operations with good crop establishment, paddocks were being grazed very evenly and shorter than usual. This was also expressed as the observed preferential grazing on Soilkee rather than non-Soilkee treatments in the trial paddocks. The cattle knew where to find the most digestible and nutritious feed. The Soilkee operation, therefore, improves plant growth over the whole paddock rather than in strips defined by the 'kee's.

August 2013. Average weight increase across all Soilkee treatments was 46% for fresh weight and 30% for drymatter weight compared to Control. The drymatter crude protein content per hectare increased by 45% compared to Control, thus fodder quality was maintained at the highest level with the large production increase. Soilkee had smaller but beneficial effects on Detergent Fibre contents, digestibility and metabolisable energy of the feed.

May 2014. Soilkee was superior to Control and Fertilizer for all quality measures and much better than in August indicating a cumulative beneficial effect of the Soilkee Renovator. Crude protein, digestibility and metabolisable energy were 20, 8 and 10% higher, respectively, and the poorly digestible Detergent Fibres 12-13% lower than Control. The production per hectare performance of Soilkee was not as good as in August since preferential grazing on the Soilkee treatments had occurred during grazing events. The differences between Soilkee by itself and Soilkee with extra inputs again were marginal and associated with poor survival of emerged seeds due to preferential grazing and dry conditions.

For the two farms with all three paddock trials sampled around 1 May 2014, the increase in average **drymatter production** for the Soilkee treatments was 8% higher than for the non-Soilkee. The percentage drymatter **crude protein content** for farm averages increased for Soilkee+Seed+Fertilizer 10% (Farm C) to 28% (Farm B) from Control, while paddock results were more variable. Fodder quality for paddocks on Farm A was more stable across treatments than on the other two farms as Farm A soils were already more healthy.

The **Acid Detergent Fibre** (ADF) content of the fodder is composed of cellulose and lignin and is relatively indigestible. Therefore, the lower the ADF the better the quality is. The Soilkee+Seed+Fertilizer treatment gave an average improvement per farm of 9 to 13% over Control. Again, paddocks at Farm A with healthier soils were more stable across treatments and had the lowest ADF. Fodder with low ADF provides more energy. The **metabolisable energy** of fodder across treatments and farms had the biggest increases due to the Soilkee operation from lower starting points at Control, with average improvement per farm between 3 and 12% (8% mean). The smallest improvement was for Farm A with the best soil health for Control.

Soil Chemistry

One of the aims of the Soilkee Renovator Project was to quantify the observed improvements in soil health and fertility. Soil samples of 15cm were collected from the designated control areas in mid-April 2013 on all paddocks, and around 1 May 2014 in seven trial paddocks for each of four treatments: Control, Soilkee, Fertilizer and Soilkee+Seed+Fertilizer. The first pair and last pair of these treatments represent for a lower and higher fertility level, respectively, comparisons between with and without Soilkee. Soil tests were done by the Environmental Analysis Laboratory of Southern Cross University in Lismore, New South Wales. Average pH (water) was 5.8, 6.0 and 5.6 for farms A, B and C, respectively.

Over thirteen months the soil chemistry for both Soilkee treatments was some 13% better than Control and 18% better than Fertilizer, being the average change in improvements for 57 measured soil chemistry factors. There were no major differences between the means of the two Soilkee treatments. This indicates again that the impact of the Soilkee operation by itself was a dominant factor in the current trials under preferential grazing and dry conditions.

Soil Carbon. The Soilkee Renovator is an excellent tillage implement for soil regeneration in Carbon Farming due to formidable carbon sequestration. The average organic carbon in the topsoil under Soilkee treatments increased with 0.9 to 4.6%, or by 23% in one year compared to non-Soilkee. Biological activity and improved carbon would have decreased the bulk density for these loams from, say 1.8 (restricting root growth) to 1.4 g/cm^3 (typical good loam) or less, and greatly increased the porosity. This could thus equate with an increase in soil carbon of some 7 t/ha. Such an increase is much bigger and faster than is being achieved under the Best Management Practice of current farming systems. It is also outstanding as these paddocks started from an already high carbon base of around 3.7%, the level in the Control/non-Soilkee treatments at 13 March 2013 and 1 May 2014.

The fraction of soil organic carbon which is easily lost, and is available for use by the microbial biomass when needed, is called **labile carbon**. The other carbon fractions are made up of the more stable humus and the inert charcoal. With the 23% carbon increase under Soilkee the composition of the soil carbon pool was kept in the optimal range with 22% in the labile pool.

The usual way for carbon reporting in farm soil tests is **organic matter**, which is obtained with a standard conversion of 1.75 from measured soil organic carbon. Averages across the 28 samples for organic matter were 6.2, 7.3, 7.9 and 7.8% for treatments Control, Fertilizer, Soilkee and Soilkee+Seed+Fertilizer, respectively. Organic Matter on these farms was relatively good with averages of 8.2, 5.6 and 7.0% for Farms A, B and C, respectively.

Cation Exchange Capacity (CEC). CEC is a measure of exchangeable nutrients in the soil potentially available to plants, that is, those held on soil particles and organic matter. The average improvement for CEC in the Soilkee and Soilkee+Seed+Fertilizer treatment was 11 and 21%, respectively, compared to Control. This increase is associated with the increased soil organic matter for the Soilkee treatments. CEC for a standard loam starts from 10 cmol/kg for an organic matter content of 3.5%, while clay has CEC values higher than 20 cmol/kg and sand lower than 4 cmol/kg. The loamy soils on the trial paddocks were already well above this benchmark for loam with for Controls an average CEC of 12.8 cmol/kg under an organic matter of 6.2%.

Extractable and Available Nutrients. Nutrients can be present in the soil but be unavailable for uptake by plants because the soil is unbalanced in its chemical-biological-physical aspects or having very high levels of particular nutrients which work antagonistically to availability of others. The total extractable nutrients, which are potentially available to plants, were quantified for the Soilkee treatment on trial paddocks sampled around 1 May 2014. Results showed many nutrients to be present in the soil but remaining unavailable. If nutrients already residing in the soil were to be made available in a timely fashion, then fertilizers used would need to include less individual nutrients and lower amounts.

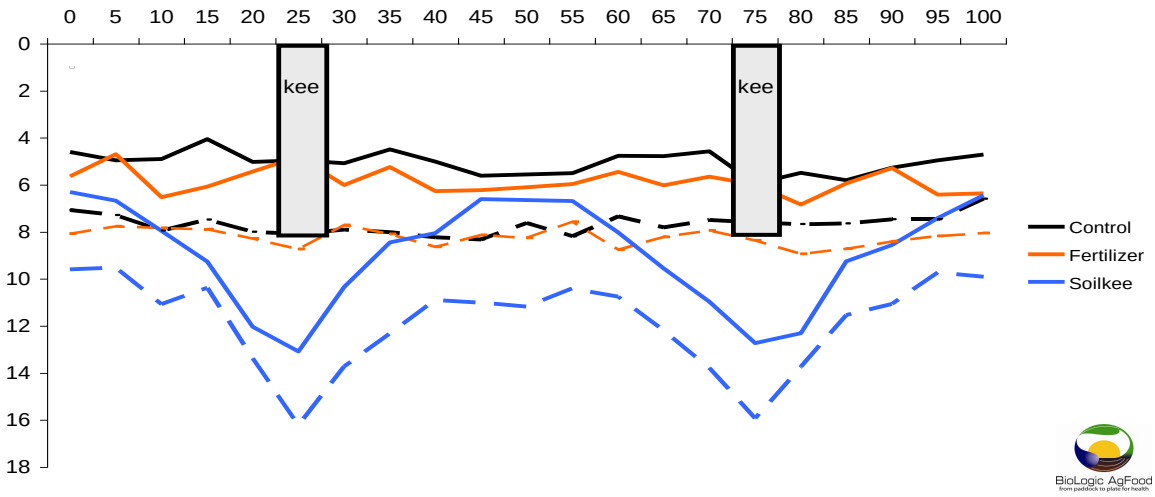
Abundance and diversity of microbes greatly improve nutrient availability. Significant improvements in nutrient availability were measured when moving from non-Soilkee to Soilkee treatments. For example, increases of 34, 51 and 122% for Phosphorus, Sulphur and Nitrogen, respectively. Such improvements are most likely associated with the Soilkee operation activating and diversifying soil microbes. Only small differences are again shown between the Soilkee operation by itself and that with added seed and fertilizer.

The quickest way to a healthy, balanced soil is by stimulating the microbiology and applying small amounts of plant-available nutrients. This allows good plant growth that feeds microbe diversity in the soil, making more minerals available and thus requiring less plant-available fertilizer in subsequent years as soil gets healthier. The Soilkee Renovator is an excellent tool to speed up this process as it activates the microbes by creating a very suitable environment for them with plenty of food, air and water.

Field observations

Soil Condition. At the end of the project soil hardness was measured with a penetrometer made of 3mm fence wire. The wire was pushed into the soil every 5 cm over a length of 1 m across the tillage direction at four locations per treatment. Figure 1 shows for three treatments the average patterns for May (broken lines) to be similar to January (solid lines), with penetrations consistently some 2-3 cm deeper following the 119 to 153 mm rainfall over that period. The deepest penetrations occurred under the two 'kee' lines where soil had been mixed in slots 8cm deep and 5cm wide by the Soilkee operation. The soil between the 'kee's was left undisturbed with a deposit of soil on its surface. It is obvious that the ensuing activation of soil biology and associated active root growth loosened the soil not just along the narrow 'kee's but also substantially between the 'kee's. Depths of penetration on Control provide the reference for improvement, with Fertilizer lessening the soil hardness slightly by plants having more vigorous root growth.

Figure 1. Average penetrometer depths (cm) for three treatments of trial paddocks on three farms for 31 January (solid) and 1 May (broken) 2014.



Root growth. After a dry summer differences in Figure 1 are relatively small. However, when soil moisture increases with depth, root growth in Soilkee treatments will advance to a greater depth, especially in and along the 'kee's. Three months after the 'kee's were created observations already showed triangular rooting patterns along the 'kee's (Photo 3) similar to the pattern in Figure 1; roots in the 'kee' went up to 24 cm deep in early August. Root growth under Control and Fertilizer will still be poor when soil


Photo 3. Roots in the 'kee'

moisture goes deeper than 10cm because the low porosity and high bulk density will restrict root growth. Deeper root depth on these paddocks has to be promoted through management for healthy soils, such as by regular use of the Soilkee Renovator. For similar soils on Farm A management for healthy soils had root depths already at 20 cm.

Earthworms. Observations around 1 May 2014 showed earthworms present in a 3 to 4 cm layer below the surface as being wet from recent rains. The average number of earthworms per dig was 2.0, 2.3 and 2.9 for Control, Fertilizer and Soilkee, respectively, on Farm C. This represents an increase of 45% due to Soilkee. Earthworms in the Control reflect the high soil carbon and good aggregation of the topsoil. From observations around 1 June 2013 Soilkee activated their presence and numbers to a greater depth then under Control. These observations, however, were not quantified but were given as a qualitative score corresponding to "worms are present" for nearly all treatments on the three farms; another indication of starting with relatively well managed soils.

Grass Fraction. New non-grasses were introduced in Soilkee+Seed treatments. The most successful species established were generally plantain, chicory and peas for the 1st, and turnip and peas for the 2nd Soilkee operation. Non-grasses established from the 1st Soilkee operation in mid-April 2013 had generally disappeared through preferential grazing or by being uprooted with the 2nd Soilkee operation in mid-November. For the final assessment in May 2014 the non-grass fraction of pasture composition was similar across treatments and Soilkee+Seed was not different. Non-grasses across the non-seed treatments generally were weeds, for example, buttercup on Farm C. Seed establishment was poorest at Farm B due to poor persistence in the dry conditions and preferential grazing.

Ground Cover. The ground cover for Soilkee treatments in January was generally some 30% lower than for non-Soilkee treatments but still mostly above the 70% generally regarded as critical. Dry conditions and grazing had slowed establishment after the re-formation of 'kee's with the 2nd Soilkee operation in mid-November. Rains since January improved ground cover in the 'kee's considerably. Ground covers around 1 May for Soilkee treatments were similar or 10% lower than non-Soilkee. Ryegrass was emerging on one farm following April rains and on Soilkee treatments seedlings were some 4 cm taller because of earlier emergence in better soil conditions.

Greenness of Cover. Observations around 1 May 2014 showed the ground covers on Soilkee treatments of the six trial paddocks on Farms B and C to be about 15% greener than Control and Fertilizer. Such slower senescence of the canopy will enhance production and make the growing season longer. The water content of fresh fodder weight for Soilkee treatments was generally 5 % higher than for non-Soilkee, thus having younger, more succulent green.

Summary

The effects of the Soilkee Renovator were quantified over thirteen months for forage and soil characteristics in nine paddock trials at three dairy or beef farms in Gippsland. Soilkee was evaluated at two fertility levels. At the low fertility level Soilkee-only was compared with Control. Fertilizer was added to control and Soilkee+Seed for evaluation at a higher level of fertility. The results 13 months after commencement of the Project transgress the low and high fertility grouping, as Soilkee-only results generally were better than the treatment with only fertilizers. Thus the Soilkee-only operation improves soil fertility.

The Soilkee operation activates soil biology greatly and considerably improved soil fertility as measured, for example, by nutrient availability, nutrient storage (CEC) and carbon content. Thirteen months after the 1st Soilkee operation soil tests showed an average 13% improvement for 57 soil chemistry factors compared to Control.

Because soil nutrient availability was better, Soilkee also improved the feed quality, making it more nutrient-dense and balanced as measured by crude protein, digestibility and available

metabolisable energy. The better feed quality was also observed by the preferential grazing of Soilkee treatments during the commercial paddock rotations on the three farms.

Summer crop can be established in a pasture with the Soilkee Renovator to bridge the autumn feed gap without loosing grazing days. The current trial could not evaluate this feeding opportunity because poor seedling survival due to dry conditions and preferential grazing after the 2nd Soilkee operation which had summer crop seeds.

Many measured traits for the Soilkee-only operation were as good as for Soilkee+Seed. This was due to poor seedling establishment and survival. Preferential grazing removed the established seed source from the 1st Soilkee operation of mid-April 2013. Poor seed establishment, preferential grazing and dry conditions over summer did the same for the 2nd Soilkee operation of mid-November 2013.

In May 2014 Soilkee treatments generally were about 15% greener than non-Soilkee. Such slower senescence of the canopy will enhance production and make the growing season longer. The water content of fresh fodder weight for Soilkee treatments was generally 5% higher than for non-Soilkee, thus having younger, more succulent green.

The collaborating farmers concluded that the pasture and soil benefits resulting from the use of Soilkee at a farm scale would result in more productive and healthy livestock, more grazing days, higher quality outputs, and lower inputs such as fertilizer and brought in feed. The results of these trials affirm the principles of moving towards healthy soils. The Soilkee Renovator proves to be an excellent tillage implement for soil regeneration in Carbon Farming. To date only proven in pastures with crops for grazing, not for grain production such as in pasture-cropping.

Management outcomes in resilient farming systems using the Soilkee Renovator would be*:*

- Improved soil fertility – less fertilizer requirement,
- Diverse pastures - summer crops to fill feed gap,
- More grazing days: longer seasons and shorter renovation time, no need to clear pastures for new planting,
- Improved soil structure, higher water holding capacity, improved water use and irrigation efficiencies,
- Less insect and disease pressure,
- Nutrient-dense, balanced feed is grazed evenly for productive & healthy livestock,
- Improved profitability: high product quality with lower inputs,
- Reduced boom-bust – lower stress levels,
- Functioning ecosystems – biodiverse landscapes,
- Increased carbon in soils and lower emissions. – easing impacts of climate change

Soil Regeneration Towards Resilient Farming Systems