# Keyline Design- water management of agricultural landscapes: Key for Regenerative agriculture?

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# Introduction

Keyline design is a planning approach that aims to contribute to sustainable agriculture by enhancing soil fertility based on landscape morphology and water inventory. Its primary goals are to improve soil structure and soil fertility as well as to increase actual depth of fertile soil (**Yeomans**, **1954**, p.9). Originated from water management techniques in the mining industry of 13$^{th}$ century, modern Keyline design is gaining attention as a tool for water management in sustainable agricultural production systems. This paper aims to draw a picture of what Keyline design is and which management practices it can include. Therefore, the origin and history of the Keyline design concept as well as recent development and application in agriculture will be presented. Potential advantages of Keyline design will be discussed as well as its limitations to answer the research question: Should Keyline design be a central management practice of regenerative agriculture?

To answer this research question, available literature will be presented and discussed. Moreover, knowledge gained from a workshop on Keyline design held by Phillip Gerhard in September 2021 will be incorporated in this paper.

# 2. The concept of Keyline Design & Regenerative Agriculture

Keyline design can be applied in both conventional or organic agriculture. However, Keyline Design is usually associated with organic agriculture. P.A. Yeoman was convinced that organic agriculture produces fertile soil and described the side effects of chemical farming methods, i.e. conventional agriculture, as “curse”. Nevertheless, he argued that organic agriculture did not encounter the issue of soil erosion (**Yeoman**, **1958**, p. 141), which is claimed to be a serious environmental and public health issue for human society (**Pimentel**, **2006**). Keyline Design adds the layer of landscaping to organic farming in order to create an agriculture that does not deplete but regenerates soil fertility.

In recent years the term *regenerative Agriculture* has received more attention as a sustainable farming approach in the literature (**LaCanne** and **Lundgren**, **2018**; **Schreefel** et al., **2020**). Regenerative agriculture can be defined as “*an approach to farming that uses soil* *conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting [ecosystem] services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production*" (**Schreefel** et al., **2020**, p.5). One of its main goals is to improve soil fertility, optimize resource management, improve nutrient cycling as well as to improve water quality and availability (**Schreefel** et al., **2020**). Regenerative Agriculture and Keyline design have overlapping goals in terms of the improvement of soil fertility, while Keyline design mainly focuses on the aspect of water availability.

## 2.1 Origin & History of Keyline Design

It is assumed that the origin of Keyline design can be found in the development of Germany's mining industry in the 13th century (**Gerhardt**, **2021**). Located in today's central Germany lies the Harz region, a low mountain range with an elevation up to 1141 meters above sea level. The Harz region used to be the most important center for pre industrial mining worldwide (**Wikipedia**, **2022**). Thereby, the main source for energy was hydro power, based on a sophisticated system of constructed water ways. This so called "Oberharzer Wasserwirtschaft", which translates to upper Harz water management, is classified an UNESCO world heritage since 2010 (**UNESCO**, **2010**).

The mining conducted in the Harz was one of the most innovative during 17th and 18th century when the industrial revolution took off in Great Britain. Hence, engineers that designed the upper Harz water management were recruited by the British empire and their knowledge spread within the anglophone world. Due to England's increasing colonization, this knowledge found its way to Australia, where it was finally applied on agricultural production systems (**Gerhardt**, **2021**). In the 1920s, the Australian P.A. Yeomans studied mining geology and worked as an engineer in the Australian mining industry for some years until he purchased farmland in 1943 (**Yeomans**, **1954**, p.4). On the very unproductive and dry site, Yeomans identified the efficient storage and transportation of water as the key to turn the unproductive site into fertile land and named his approach to water management in agriculture Keyline design (**Yeomans**, **1954**, p.5).

## 2.2 The Keyline scale of relative permanence

According to P.A. Yeomans, Keyline Design aims to conserve as much water as possible from precipitation in the soil. If the soil is saturated with water, the excess water is conserved in various dam structures on the farm (**Yeomans**, **1958**, p.20). The planning approach is based on the Keyline scale of relative permanence, which includes different abiotic and biotic factors that influence agricultural land. Thereby, the scale is organized according to which extend each factor can be influenced and how permanent the respective factor is. On the top of the scale is the factor which can be influenced the least and is the most permanent, i.e. climate. The influenceability of the respective factors increases towards the scales' bottom. The Keyline scale of permanence is displayed in table 1 including updated versions.

| Yeomans (**Yeomans**, **1958**, p.37) | Doherty (**Chabay** et al., **2016**, p.295) | Gerhardt (**Gerhardt**, **2021**) |
|---|---|---|
| 1. Climate | 1. Climate | 1. Climate & Culture |
| 2. Land shape | 2. Geography | 2. Geography |
| 3. Water supply | 3. Water | 3. Water |
| 4. Farm roads | 4. Access | 4. Access |
| 5. Trees | 5. Forestry | 5. Vegetation |
| 6. Permanent buildings | 6. Buildings | 6. Buildings |
| 7. Subdivision fences | 7. Fences | 7. Borders |
| 8. Soil | 8. Soil | 8. Soil |
| | 9. Economy | 9. Economy |
| | 10. Energy | 10. Energy |

*Table 1: Keyline Scale of relative permanence*

Yeomans' keyline scale of permanence from 1958 was recently updated by Darren J. Doherty and Phillip Gerhardt. Doherty was trained by Yeoman and is the founder of the Australian consultancy for regenerative agriculture *Regrarians*. Gerhardt implements Keyline design and Agroforestry systems by consulting and supervising agricultural production sites in the German speaking area of central Europe with his company *Baumfeldwirtschaft*.

## 2.3 Keypoint and Keyline

Identifying a Keypoint in a landscape is the basis for Keyline design as it has been described by P.A. Yeomans. However, there is not a clear definition of where exactly a Keypoint is located. After Yeomans, a Keypoint marks a location in a landscape where the topography of a valley changes from being narrower and steeper to being wider and flatter than the adjacent ridges of the valley (**Yeomans**, **1954**, p.10). In other words, the Keypoint is located where the slope changes from being convex, where water runs, to concave, where water collects. It is therefore also a point where sedimentation starts and water accumulates.

A Keyline is a contour line which is on contour with the Keypoint, i.e. on the same elevation level. This particular contour line is the reference for the cultivation pattern lines, which are set parallel to the reference contour line ascending and descending from the Keyline (see figure 1). The parallel cultivation pattern is a major advantage of Keyline Design, as it allows machinery to evenly work with the same adjustments.

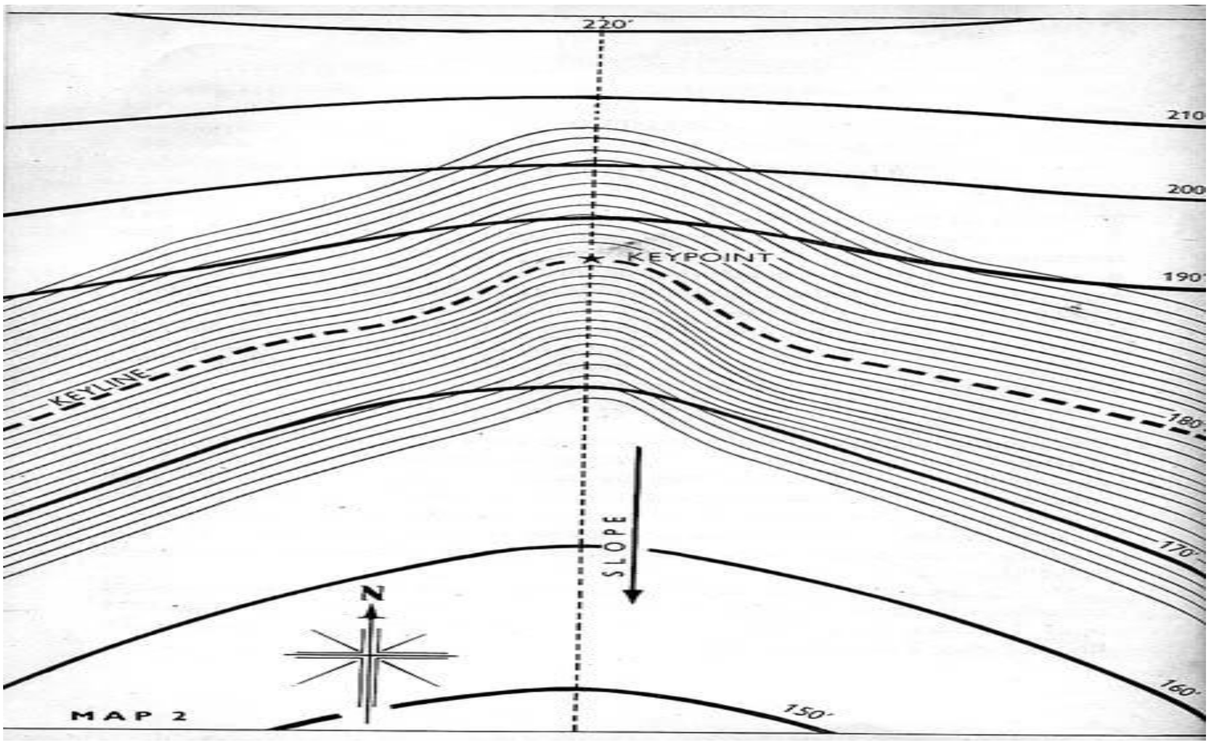


*Figure 1: **Basic map of a valley with contour lines**. The level of elevation for the respective contour line is displayed on the right end of each contour line. The star marks the Keypoint and the dotted line that runs through the Keypoint is a contour line and the Keyline. Note that all other lines drawn parallel to the original Keyline form the cultivation pattern. The slope starts to flatten downhill from the Keyline, which can be seen in the increasing distance between the contour lines (**Yeomans, 1954**, p.14).*

## 2.4 Yeomans Plow

In Keyline Design, tillage is implemented using the so called Yeomans Plow. This machinery is based on a simple chisel plow and aims to progressively deepen soil cultivation (**Yeomans**, **1954**). Thereby, the goal is to create channels in the soil to improve water infiltration and aeration as well as stimulation of root growth while reducing soil disturbance to a minimum (**Rhodes**, **2017**). It has also been reported that Yeomans attached a vibration tool to the plow to further reduce resistance and help with breaking up the soil (**Hill**, **2002**).

The Yeomans plow does not turn but simply breaks up and loosens the soil. Hence, the effect and aim of a Yeomans plow is very similar to a subsoiler. However, a Yeomans plow is usually set to reach just 2-5 centimeters below the existing root layer and is designed with lighter shanks ("Schare" in German). Therefore, the energy required to break up the soil is less than with a common subsoiler (**CrKeyline**, **2022**).


*Figure 2: **Yeomans Keyline plow** (Hokonui.com, 2014).*

On pasture, the cultivation pattern with the Yeomans plow, or an adjusted subsoiler, is repeated annually for usually three years. Hence, the roots can progressively penetrate deeper into the soil (**Hill**, **2002**). Even though it has been stated that commonly used subsoilers can create the same effect as the Yeoman plow (**Gerhardt**, **2021**), a lot of work has been put into developing adapted versions.

The agriculture consultancy company *Regrarians*, founded by Darren Doherty, received their first Yeoman plow in the mid-90s. The first adaption was the attachment of a rotary cultivator ("Bodenfräse" in German) behind the subsoiling shanks to mechanically cultivate the grass sod and prepare the soil for forestry and viniculture. After a few years, the machinery was further complemented with a set of 26" discs attached behind the rotary cultivator, which made it possible to mound at the same time and improve seedbed preparation. Later, a rotary cultivator was developed that could realize bed forming, which made the discs obsolete (**Doherty**, **2017**).

At this point the adapted Yeoman plow could rip, i.e. subsoil, as well as mill the soil and prepare seed beds. In 2008, the first Keyline SuperPlow prototype was developed, which also injects biofertilizers and is able to drill seed (**Chabay** et al., **2016**, p. 277). The Keyline SuperPlow was further improved to function more efficient in the following years resulting in the MK3 version in 2017 (**Doherty**, **2017**).

# 3. Development and recent application of Keyline design in agriculture

After having described the concept of Keyline as it was formulated and implemented by P.A. Yeomans, this chapter will provide an insight on practical implementation of Keyline design in recent years.

Keyline design as it was adapted on agriculture by Yeomans has been further developed in recent years. Pioneers of modern Keyline Design such as Mark Shepard in the U.S.A., Phillip Gerhardt in Germany and Darren Doherty in Australia do not apply Keyline Design in a classical manner after Yeomans. They concluded that following strictly Yeomans approach would not work on a complex landscape and requires adaptation (**Shepard**, **2022**; **Gerhardt**, **2021**; **Doherty**, **2016**). Different approaches of adapted Keyline Design are described in the following subchapters.

## 3.1 Master line system

**Primary valley cultivation pattern**

The cultivation lines are set parallel to the Keyline descending down the valley (see figure 3). However, in some landscapes, following cultivation patterns based on a geographic Keypoint results in an accumulation of waterflow in the primary valley. Here, adaptation of the primary valley cultivation pattern is needed.  The goal of Keyline design is to evenly distribute the water in the landscapes, which also means to guide water flows concentrating in the valleys to the ridges (**Gerhardt**, **2021**). In essence, the Keypoint is moved in order to define parallel cultivation patterns which guide the water towards the ridges and prevent water erosion (see figure 4).

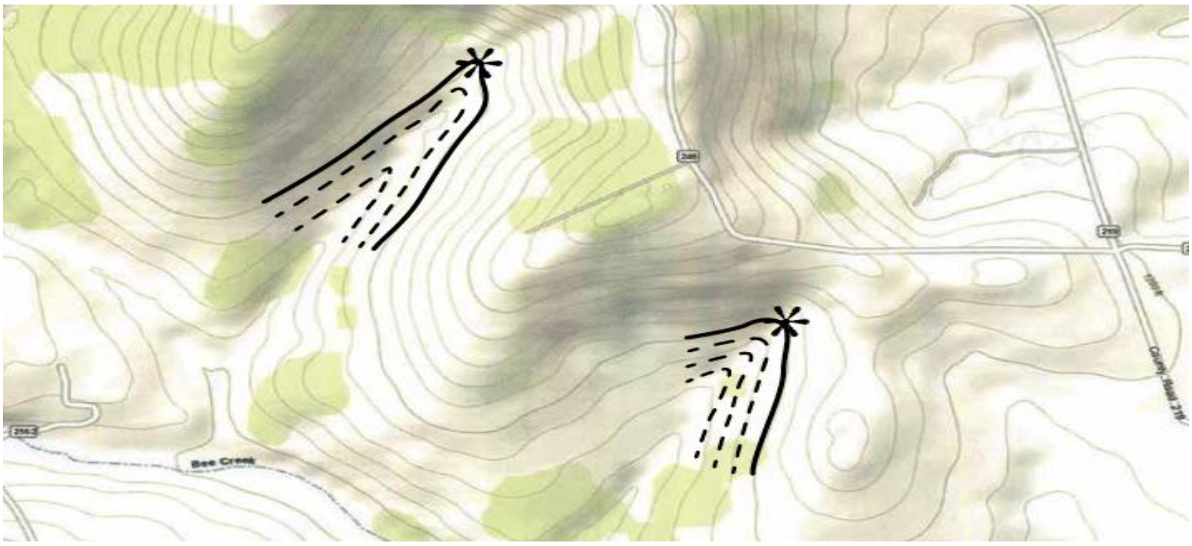


*Figure 3: **Classical primary valley cultivation pattern.** The star marks the Keypoint, the bold line the Keyline. The dotted lines represent the cultivation pattern parallel to the Keyline. (**Shepard**, **2022**)*

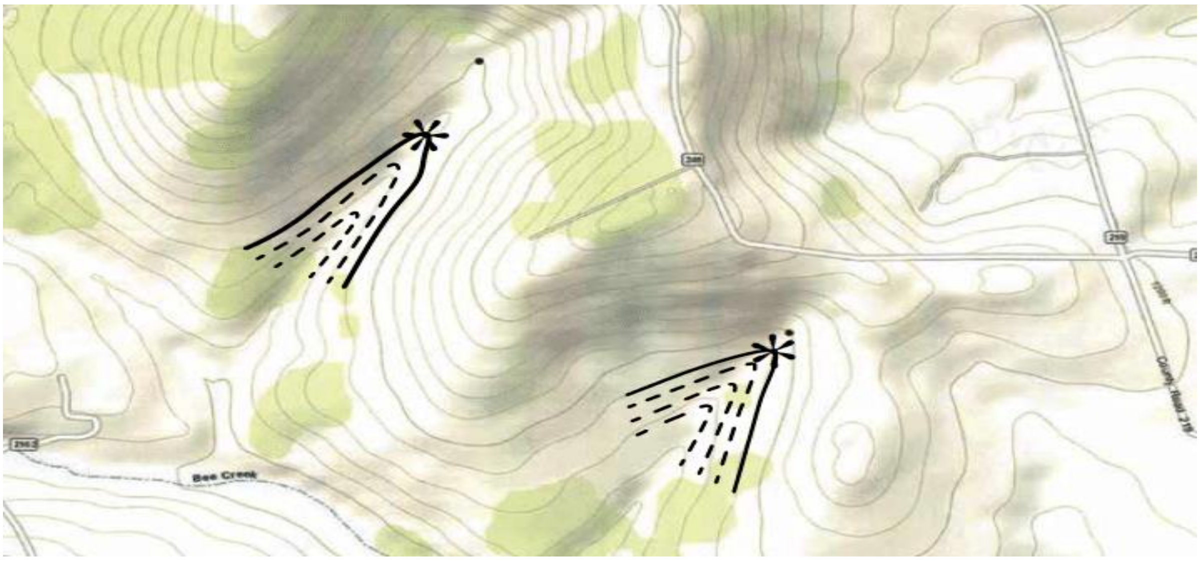


*Figure 4:* ***Adapted primary valley cultivation pattern*** *The Keypoint was moved down to realize a cultivation pattern that guides the water to the ridge. (**Shepard, 2022**)*

**Primary ridge cultivation pattern**

In this case, a contour line with the lowest practical elevation is the reference Keyline for the primary ridge cultivation pattern. Here, the cultivation pattern is applied parallel to the Keyline and uphill towards the ridge (see figure 5). Following strictly this pattern can result in the slopes of the cultivation lines being too steep, hence causing erosion. In some geographical context, the issue of water erosion would simply be transferred from the valley to the ridges,

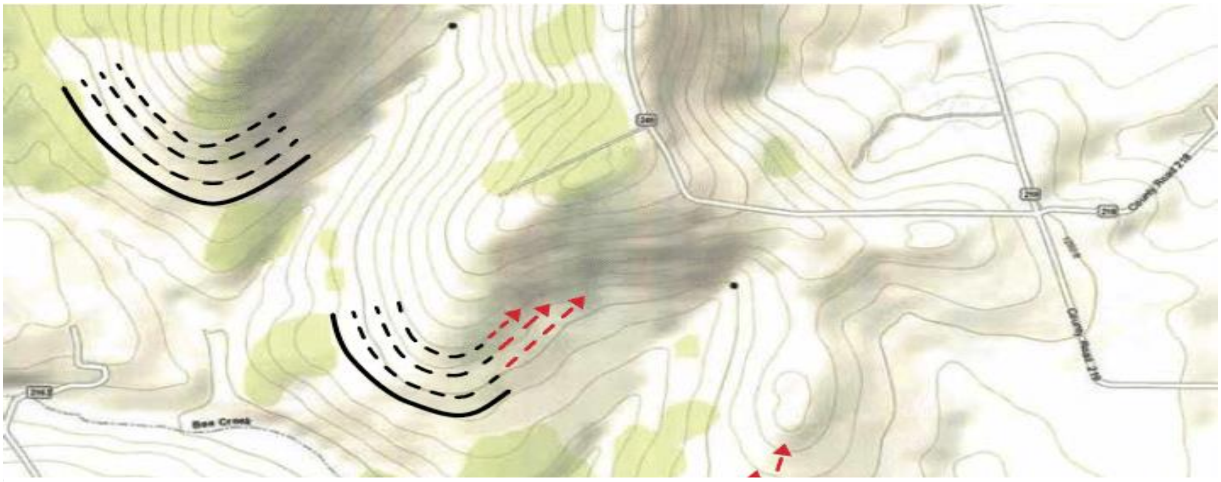


*Figure 5:* ***Classical primary ridge cultivation pattern****. The lowest practical contour line is the respective Keyline. In the centre valley and in the valley on the right, this cultivation pattern would cause erosion, expressed by red arrows. (**Shepard, 2022**)*

but not be solved. Therefore, the reference contour line is moved up to find a contour line that does not result in a cultivation pattern that is too steep (see figure 6). In some cases, moving up the reference contour line solves the issue of water erosion. However, in some cases a ridge does not obey Keyline geometry and the issue of soil erosion is not solved just by moving up the reference contour line. Here, more adjustment is needed.

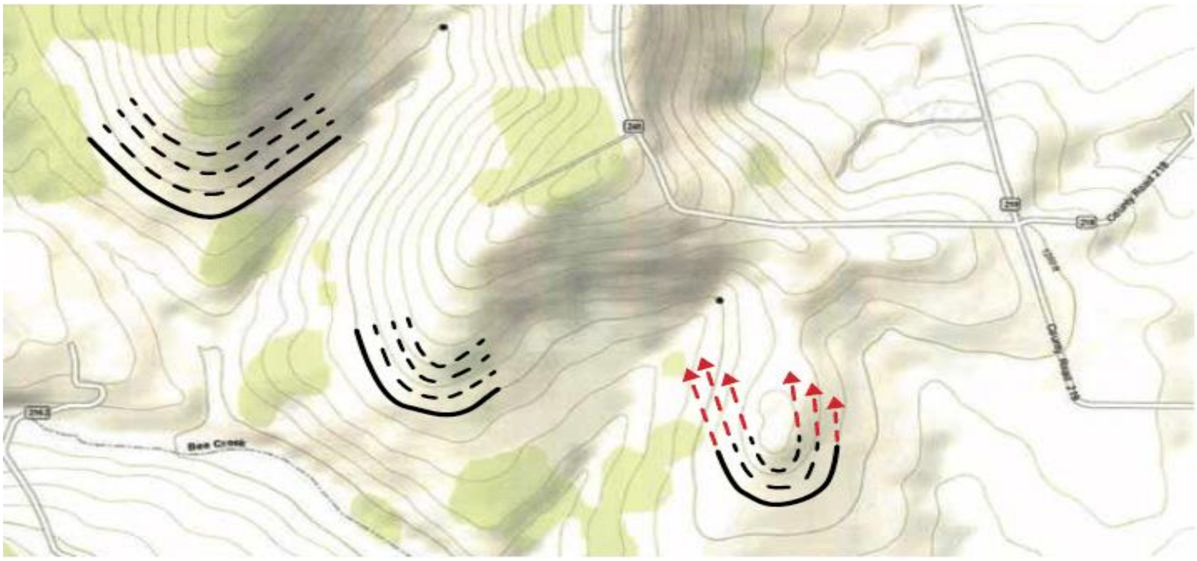

*Figure 6:* ***Adapted primary ridge cultivation pattern*** *The reference Keyline was moved up for the centre valley and the eastern valley to flatten the slope of the cultivation pattern. Note that in the valley on the right, the slope is still too steep. (**Shepard, 2022**)*

Conclusively, the adjusted primary valley cultivation pattern is combined with the adjusted primary ridge cultivation pattern to guide the water to the ridges instead of letting it drift to the valley (see figure 7). The combination of both cultivation patterns merges into a coherent cultivation line, which is also called the guide line (**Doherty**, **2016**).

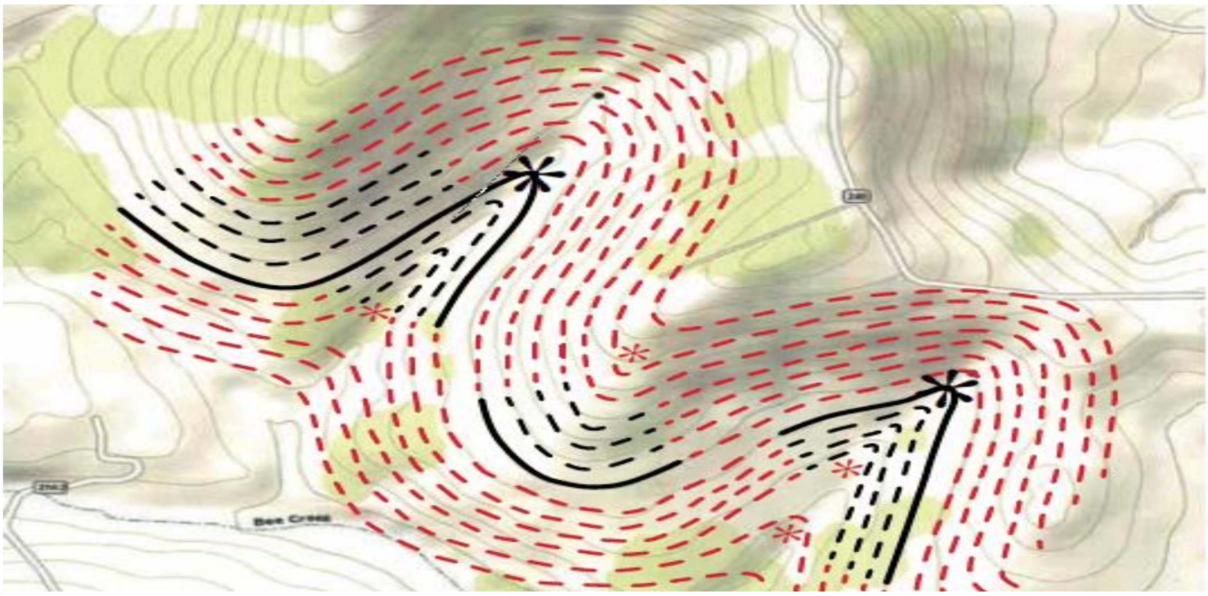

*Figure 7: **Combined primary valley and primary ridge cultivation pattern.** The results is a cultivation pattern that considers the special geographical features and guides water from the valley to the ridges. (**Shepard, 2022**)*

As a consequence of following parallel cultivation lines, the area for turning the machinery gets smaller and eventually it is impossible to turn. Hence, spots of uncultivated land appear, which need to be designed according to the respective conditions and needs (**Gerhardt**, **2021; Doherty**, **2016**). These spots could be filled with a woody landscape structure that function as an ecological hideaway as well as an area for agricultural use, such as the deposition of wood chips from cuttings of perennials in an Agroforestry system.

The explained Master line system is similar to the Main line system which was developed at the same time by Phillip Gerhardt and is described in the next subchapter.

## 3.2 Main line system

In this approach it is also not the main focus to identify the Keypoint and the respective Keyline. In fact, a cultivation line, i.e. the mainline, is identified where the parallel offsets will bring the desired effect of equally distributing water in the landscape. While the classical Keyline only achieves the desired effect if there is a slope, this mainline system also works without a distinct slope (see figure 8). It is crucial to also consider the present cultivation pattern. Here, the main lines are adapted to prevent water accumulation in the headland (see figure 9).

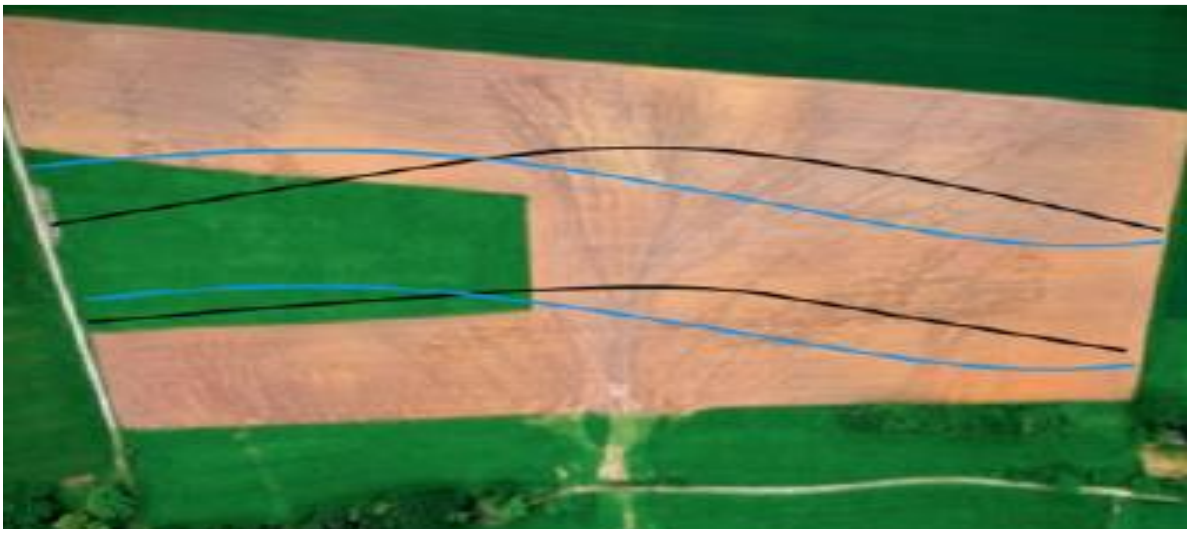

*Figure 8: **Basic Main line system.** The black lines are contour lines. Blue lines represent the main lines which define the cultivation pattern. Note that the main lines are parallel to each other and intersect with the contour lines. (**Gerhardt, 2021**)*

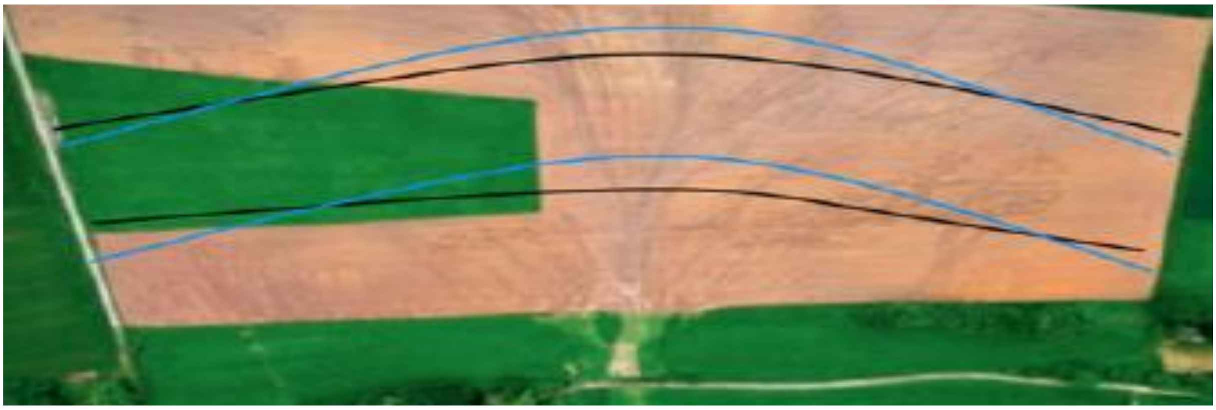

*Figure 9: **Adapted Main line system.** The cultivation pattern is adapted to prevent water accumulation and erosion in the headland. (**Gerhardt, 2021**)*

The Main line system can be applied with a simple subsoiler while remaining the former cultivation system. However, it is very advantageous to combine this adapted Keyline design with a fundamental change of the field structure with swales and Agroforestry systems.

## 3.3 Implementation of modern Keyline design

Depending on topography and soil type, swales can function as water distribution channel or simple infiltration bodies. However, the construction of swales is labor intensive and their necessity needs to be assessed on every site. In many cases, using a subsoiler adapted to Keyline design is sufficient to distribute the water evenly in the landscape.

It is crucial to calculate the amount of water that is expected to accumulate on a given slope. The steeper a slope, the shorter is the distance that water can be allowed to flow before severe gully erosion appears. Other factors, such as vegetation cover or tillage also need to be put into consideration.

Agroforestry systems, i.e. the deliberate usage of woody perennials on the same site as agricultural crops and/or livestock (**FAO**, **2015)**, are especially eligible to be combined with the construction of swales and Keyline design. The trees are planted along the swales on the descending site. Thereby, the water availability of the roots is improved and especially on steeper slopes, soil erosion is further prevented (**Gerhardt**, **2021**). The intergovernmental panel on climate change (IPCC) states that Agroforestry systems can enable sustainable intensification of agricultural systems and provide additional ecosystem services (**Olsson** et al., **2019**).

Moreover, a case study conducted on a farm in Australia found that the application of Keyline design can be a key element for successful water management and tackling desertification (**Chabay** et al., **2016**, p. 273). Keyline Design, amongst other management practices, accelerates soil building activity, which results in an increase in carbon matter and soil water holding capacity. In this case, also dams and swales are incorporated in the Keyline Design to optimize water conservation and distribution (**Chabay** et al., **2016**, p. 276). The management practices on the farm were, among others, designed by Darren Doherty who also understood Keyline Design more like a holistic system approach (**Doherty**, **2016**).

Successful Keyline design has to be adapted to the respective site and needs of the agricultural system, also considering cultivated crops. Thereby, it is important to physically visit the site before starting the long planning process and supervise the system also after implementation.

## 3.4 Regenerative water management

Keyline Design is considered to be rather a design principle than a fixed design concept, which should be combined with other regenerative management practices. For example, reduced tillage, i.e. no plough tillage with milling, in combination with mulch application can improve water retention capacity of the soil (**Alliaume** et al., **2014**). Especially in the top soil, mulch can have a positive effect on the soil moisture and water reserve (**Kesik** et al., **2007**; **Mulumba** and **Lal**, **2008**), but also overall soil moisture can be improved by mulch (**Chalker-Scott**, **2007**) as well as water infiltration (**Adekalu** et al., **2007**).

However, such management practices do not consider the influence of cultivation patterns and landscape structure on water availability and soil fertility. Eventually, Keyline design covers the planning of whole landscapes including roads, water pipes and ponds (**Doherty**, **2016**). Changing the landscape structure in an agricultural system can be very challenging due to existing structural elements or fragmentation of the land. However, the Keyline principles can be applied in every context. It is vital to distinguish between cases where it makes sense to significantly change the landscape and cases where simple subsoiling on a cultivation pattern that distributes the water more evenly is sufficient.

## 4. Conclusions & Outlook

The fact that regenerative agriculture is a relatively new term and receives more attention, offers the possibility to reconsider which aspects are key for its success. Understanding agricultural systems on a landscape level and optimizing the water availability are such a key. Thereby, Keyline design can function as a guide to plan cultivation patterns as well as to redesign whole landscapes.

Moreover, annual cropping systems that apply other regenerative management practices can benefit from adapting cultivation patterns according to Keyline design. Here, more research is needed to investigate the effect of cultivating according to Keyline design in combination with other regenerative management practices, such as reduced tillage, mulch application, compost application or application of biofertilizers with effective microorganisms.

Considering landscape structures as highly influenced by human activity and very impactful on water availability as well as soil fertility is key for regenerative agriculture. If Keyline design is applied in combination with other regenerative management practices, it can be a central management practice of regenerative agriculture. Especially applied in an agroforestry system, Keyline design fosters the regeneration of soil fertility and improves the resilience of agricultural landscapes.

Furthermore, optimizing water distribution in a landscape with Keyline design can also be applied in terms of flood protection. With more severe weather events and heavy rainfalls, preventing water accumulation and water erosion can be a matter of life and death. The same applies to the fertility and health of soil which is highly dependent on a factor that is relatively easy to influence and still quiet permanent: water.

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